Survey of Air Quality Monitoring

Draft Report

Prepared for review by
Committee on Environment and Natural Resources Research (CENR)
Air Quality Research Subcommittee (AQRS)

May 2009

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Executive Summary -- Survey of Air Quality Monitoring

Air quality monitoring is an irreplaceable source of information for the understanding of atmospheric pollution needed to effectively develop and implement public policy. Several hundred million dollars are allocated annually to maintain and operate the nation's fixed monitoring networks, short-term field studies, and satellite remote sensors. However, the full value of data from these efforts is not realized. Each type of monitoring data has inherent limitations. Institutional barriers and resource limitations currently impede our ability to maintain current observational capacity, synthesize observations of various types and from different agencies, and adapt current systems to meet observational needs as our understanding of air quality improves and the atmosphere changes.

The value of air quality observations can be enhanced by coordinating the planning and shared operations among federal agencies, which often have compatible monitoring requirements. Coordination of measurements also facilitates intercomparison of data, allowing limitations inherent in data types to be addressed and more value to be realized from observations. We recommend creation of a multi-agency task force authorized (and with adequate resources) to identify measurement gaps to be addressed by member agencies. The task force would also focus on making monitoring data more available, interoperable, and usable, and on adapting monitoring networks to emerging issues.

This report addresses a variety of air quality measurement programs which include: routine regulatory and deposition networks, intensive field studies, remote sensing systems, sondes, aircraft campaigns, satellites, and fixed-site special purpose networks. Based on an analysis of these programs, this executive summary enumerates observational needs and issues, opportunities, and barriers to progress in positioning monitoring programs for assessing current and emerging air quality issues. Recommendations are made that should be useful to senior managers and resource decision makers at federal agencies engaged in air monitoring programs (e.g., EPA, NOAA, NASA, USDA, DOE, DOI) and associated State, local and tribal partners.

ES.1 Observational Needs and Issues

1. With the success of local and regional emission reduction efforts, distant/international pollution and natural sources have greater relative impact on air quality. These are not well characterized by existing monitoring networks.
2. Some air pollution health effects are likely much greater near certain sources, such as major roadways, while routine air quality monitoring is typically conducted at fixed sites, further away from these sources.
3. Our understanding of atmospheric and deposition processes is insufficient to allow models alone to guide many important air quality decisions.
4. Satellite remote sensing observations also have inherent limitations, and particularly require intercomparison with fixed-network and short-term field monitoring and model data.
5. Coordinated atmospheric, deposition, and effects monitoring is needed to understand deposition impacts on aquatic and terrestrial ecosystems.

6. Global climate change will change pollution emissions and air quality patterns; monitoring networks must document and adapt to these changes.
7. Monitoring programs need to be developed to track the progress of future emissions management programs for climate forcing pollutants.

ES.2 Opportunities

1. Satellite remote sensing of air quality and emissions is rapidly maturing in its capability to augment and extend the spatial and temporal coverage of networks of fixed site monitoring and special studies.
2. Air quality simulation models are able to augment observations with credible spatial, temporal, and compositional information lacking in the measurements.
3. Enhanced access to monitoring data, metadata, and processing tools provides an efficient mechanism to harmonize data from disparate monitoring and assessment programs and data of various types.

ES.3 Barriers to Progress

1. Federal budgeting practices do not adequately address long-term maintenance and updating of monitoring infrastructure.
2. Agencies often support their own priority programs at the expense of joint efforts that may have a greater overall national interest (e.g. very few data are available to characterize the increasing concentrations of pollutants transported across the Pacific.)
3. Use of data from advanced technologies, including satellites, is retarded by inadequate resources for transferring data and tools for data manipulation to the user community.
4. Weak market incentives inhibit the commercialization of advanced methods in the absence of a government mandate of the method.
5. Insufficient funding priority is given to precursors of ozone and particulate matter, which must be monitored to assess emissions control strategies.

ES.4 Recommendations

1. Establish a standing multi-agency observations task force that reports to senior managers and/or resource decision makers, and

    a. conducts periodic monitoring adequacy reviews,
    b. identifies gaps and overlaps among programs,
    c. encourages cooperation and coordination among government programs,
    d. establishes minimum standards for program design/implementation,
    e. promotes the use of common data formats and communications protocols,
    f. reviews / recommends use of new monitoring technology.

2. Address current observation gaps that require action in part to:

a. initiate monitoring of reactive gas and particulate nitrogen compounds, which are precursors of ozone and particulate matter, precursors of acid deposition, and act as nutrients in ecosystems,
b. collocate instrumentation at core monitoring sites to facilitate inter-comparison with satellite observations,
c. expand monitoring in rural/remote areas to measure regional backgrounds and contributions from long-range transport of pollutants,
d. establish monitoring in near-source areas to track trends and better understand observed near-source health effects, and
e. expand intensive field studies designed to elucidate critical processes that determine atmospheric concentrations of ozone and particulate matter and other air pollutants.

1. Introduction

1.1 Background

Actual measurements of ambient conditions are key to our knowledge of atmospheric pollution and play important underlying roles in a variety of environmental assessments. The establishment of health standards and development of emissions reduction policies rely on a wide body of observational evidence, as does the subsequent tracking of environmental progress resulting from changes in technologies, economics and environmental regulations. Because a variety of federal agencies and organizations share common information needs, opportunities exist to increase the value of air quality observations by integrating them across environmental media, pollutant categories, and spatial scales. Among these common needs is a recognition of the important interactions between air quality and climate and the ability of measurement systems to establish adequate baseline and tracking capabilities in advance of deployment of expected major energy and environmental policy shifts. Such improvements in our ability to make and utilize ambient measurements are thematically consistent with recommendations by the National Research Council (NRC, 2004) on improving air quality management practices. Against this backdrop of demands for sound air quality measurement programs are an array of resource, technological and institutional barriers compromising the maintenance and evolution of measurement networks within and outside North America.

Ambient air quality observations include a variety of surface-based networks, specialized field campaigns and satellite missions that measure trace gases, aerosols and precipitation chemistry throughout the vertical extent of the atmosphere, largely focused within the lower troposphere (planetary boundary layer generally less than 2000 m). Observations in the broadest sense are used to characterize and explain current and changing environmental states and provide a basis for:

1. Associating human health and environmental welfare effects with air quality, which is the basis for developing U.S. National Ambient Air Quality Standards;
2. Determining an area's compliance with standards;
3. Developing emission reduction strategies by supporting source apportionment studies, air quality model evaluation and application;
4. Assessing progress in response to implemented emission strategies;
5. Forecasting air quality to inform the public of adverse air pollution exposures; and
6. Elucidating atmospheric processes to improve air quality modeling systems.

This report on ambient measurement systems is intended to (1) describe the basic content (i.e., measurement parameters, locations, sponsoring organizations) of air monitoring in programs, mostly in the United States; (2) identify opportunities to enhance the value of these measurement programs through inter-agency cooperation and collaboration; and (3) advocate for sustaining and improving our nation's observation systems. The targeted audience is extremely broad and includes policy and decision makers as well as a broad

technical community of university, private sector and government researchers and technical staff engaged in environmental assessment. To communicate to this diverse audience, this summary report expands the discussions on issues and recommendations, while the appendices provide a more comprehensive summary inventorying current monitoring networks and existing observation programs.

1.2. Current and emerging air quality assessment challenges

Over the last two decades, air quality management in the United States has focused on regional scale air pollutants such as ozone, $PM_{2.5}$ and acid deposition, all of which remain issues of concern for the foreseeable future. Traditional management strategies typically take an independent pollutant specific approach. In contrast, emerging challenges in air quality management are influenced by an assortment of factors requiring a more comprehensive (Figure 1) and well integrated assessment framework:

- Multiple pollutants – Several pollutants are emitted by common emission sources, and participate in similar atmospheric chemical and physical transformation and fate processes. Our current air quality standards setting process and air quality management framework based on the Clean Air Act are focused single pollutant programs.
- Multiple environmental media – Terrestrial and aquatic systems are major sinks for air pollutants, and the re-emission of pollutants to the atmosphere through vegetation, soils and aquatic systems suggests that these linkages require a broader perspective in environmental management which traditionally addresses issues on an isolated media basis. Examples include: atmospheric deposition of excess acids, nutrients and PBTs; re-emission of deposited mercury and persistent organic compounds (POPs); and meteorological and atmospheric chemistry influences on biogenic emissions.
- Multiple spatial scales – The increasing contribution of continental scale transport to regional and urban air quality parallels a heightened concern of complex near source/roadway environments where greater relative population exposures are experienced. These spatial scale issues at opposite ends of the spectrum challenge a framework that has emphasized regional air quality management over the last two decades.
- Climate-air quality interactions – The bi-directional impacts between air quality and climate change increasingly will be incorporated in environmental assessments. A variety of emissions, atmospheric chemistry and transport processes are modified by climate change, and air quality changes impact climate processes. Consequently, emerging energy policies designed for moderating climate and policies designed to improve air quality are intrinsically connected, and measurement system design should account for this air quality-climate interplay.

Threaded throughout these emerging challenges is the role of observations in accountability analyses which attempt to assess progress of air quality management policies and regulations. Observation strategies should enable detection of expected

modifications in atmospheric chemistry brought on by changing technologies and fuels, energy policies addressing climate change and source specific control technologies.

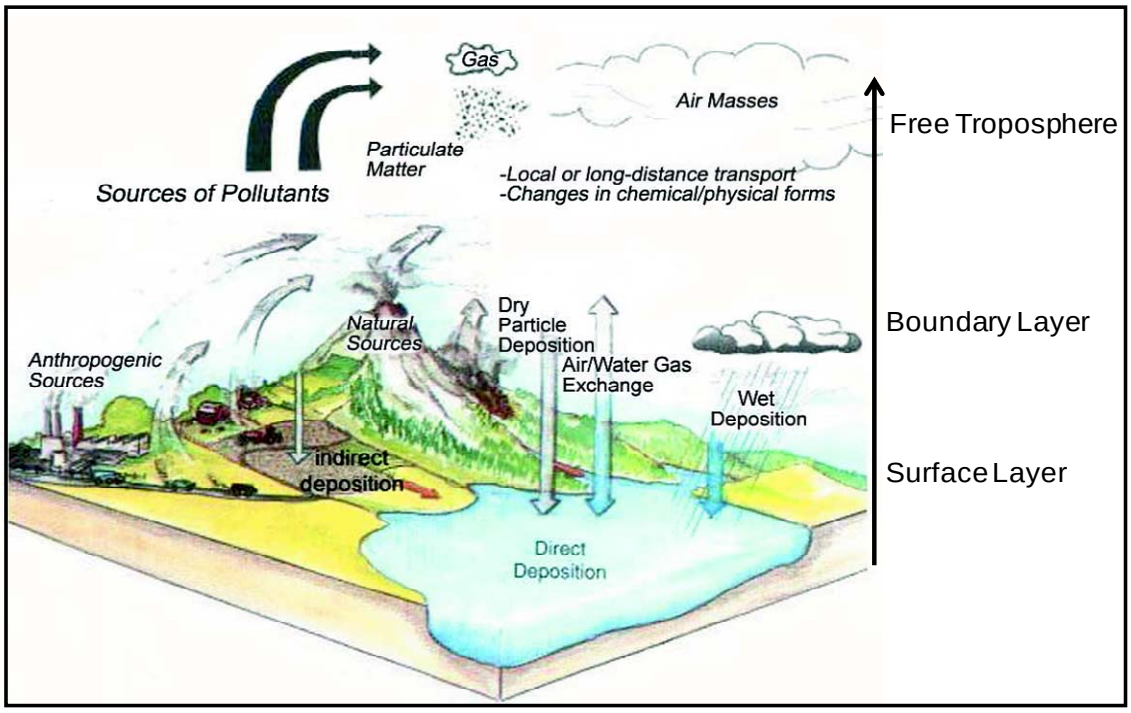

Figure 1. A variety of natural and anthropogenic processes acting across multiple horizontal and vertical spatial scales and across atmospheric and terrestrial and aquatic media share numerous co dependencies,that benefit from coordinated observation programs. Many of these processes are affected by changing climate scenarios and, in turn, contribute to climate modifications. (after NARSTO, 2009).

In addressing these challenges, consider the following developments that elucidate several of these integrated air quality management issues. There will be increased efforts in combining the complementary powers of deterministic air quality models and observations to address the complexities of scales, pollutants and media. Clearly, prospective observation systems design should recognize the linking of models and observations explicitly, a departure from the traditional separation of modeling and monitoring functions within organizations. A rethinking of our observational infrastructure should enhance the evolution of our assessment capabilities to address challenges.

Transcontinental pollutant transport and rising background levels. Air concentration levels of high volume pollutants such as ozone and $PM_{2.5}$ in the United States have been decreasing over the last decade (EPA, 2008). However, the perceived associated unit mass risk to these pollutants continues to rise as epidemiologic findings continue to demonstrate human health effects at lower concentrations and increasingly stringent ozone and aerosol national ambient air quality standards (NAAQS) are established. In turn, the relative importance of pollutant transport across U.S. borders

from expanding world development is magnified by both the decreasing level of standards and the pinching down of U.S. based pollution.

Near source and local scale challenges. There are increasing local scale and near source air quality challenges related to traditional criteria pollutants, specific components of aerosols and air toxics. For example, a majority of the North American population live within 500 m of a major highway, a very complex air quality environment subject to relatively rapid transformations of aerosols and gases. Consideration of adapting new measurement designs incorporating mobile platforms and periodic operation schedules would overcome limitations posed by traditional, fixed site reference level monitoring.

Multiple media assessments. Beyond addressing spatial and temporal features of ambient environments, integration with aquatic and terrestrial systems through atmospheric deposition processes and re-emitted pollutants will challenge observation systems to adequately characterize rural environments and pollutant categories of importance to environmental welfare effects. The linkage across the atmosphere and terrestrial systems will be influenced strongly by climate change induced effects on emissions and air quality. And, our observation systems will be expected to assess progress of traditional air quality management programs and regulations, as well as policies addressing climate forcing gases and aerosols.

Multiple pollutant characterization. Air quality management is attempting to move toward a multiple pollutant framework. The technical basis to move from a single pollutant to a multiple pollutant framework is based on a commonality of sources, atmospheric processes shared by many pollutant species. How well structured are our measurement programs that have emerged largely from single pollutant planning processes to support multiple pollutant assessments?

Climate-air quality interface. Linkages between climate and air quality are similar to common sources and atmospheric processes that link multiple pollutants. Climate forcing gases such as carbon dioxide and methane are emitted from sources that also emit precursors and direct emissions for ozone and particulate matter. Common air pollutants such as ozone, elemental carbon and PM2.5 influence climate through modifying heat budgets and cloud formation processes. In turn, temperature and water vapor related climate changes impact atmospheric chemistry reactions and emission releases that affect secondarily formed pollutants and their response to precursor change. Many of the emissions mitigation strategies targeting greenhouse gas reductions to address climate change will affect a variety of directly emitted air pollutant and precursor emissions. From an air quality observation perspective, many of the measurements servicing air pollution assessments are impacted by climate-air quality interactions, and measurement design will be challenged to assist in detecting signal changes associated with these influences.

1.3 Relationship to other strategies and organizational structures

Over the last several years a number of observational strategies and umbrella organizations have formed that convey a variety of themes addressing integration across disciplines and organization, including:

> **GEO/GEOSS** – The Global Earth Observation System of Systems (GEOSS - http://www.earthobservations.org/geoss.shtml) is an overarching framework coordinated by the Group on Earth Observations (GEO), a voluntary partnership of governments and international organizations. GEOSS is multidisciplinary, addressing a variety societal benefits cutting across terrestrial, oceanic and atmospheric environments. Since 2005, GEOSS has spurred a variety of U.S. programs in NASA, NOAA and EPA intended to link a range of air quality observation systems and facilitate information access through information technology standards and prototype systems.
>
> **IGACO/IGOS** – Integrated Global Atmospheric Chemistry Observations - http://www.igaco-o3.fi/linked/en/IGACO_Theme_Report_wmo_gaw159.pdf - is the primary air quality theme within the International Global Observing Strategy (IGOS). IGACO/IGOS provides specific recommendations on measurement parameters and facilitates integration across satellite and ground based stations. Although IGACO is focused on large global scale characterizations, the strategy provides useful guidance that should be considered in any air-based observation program design. Several of the core IGACO measurement parameters (O3, CO, NO2, CO, CO2) are important regional- and urban-scale air quality-climate indicators.
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> **GEMS (Global Environmental Monitoring using Space and in-situ data,** http://gems.ecmwf.int/**).** GEMS is an organizing structure for several European based agencies. Satellite data, ground based, and aloft in-situ observations are integrated with air quality modeling to support climate-air quality and regional air quality assessments, and air quality forecasting.
>
> **NAAMS** – The National Ambient Air Monitoring Strategy (NAAMS) was developed jointly by the EPA and numerous State and local agencies. Developed in the early 2000's, NAAMS (Scheffe et al., 2009) was intended to achieve efficiencies in the deployment of U.S. based regulatory-based networks supporting development of national air quality standards and emission control strategies. The multiple pollutant National Core (NCore) network emerged from the NAAMS process.

This report, prepared under the auspices of the Committee on Environment and Natural Resources Research (CENR) / Air Quality Research Subcommittee (AQRS), is broader than the scope addressed in the NAAMS for routine networks, though its focus is on United States federal agency programs. Section 2 includes a broad overview of air quality monitoring and observation programs that include routine surface-based

networks, intensive studies, vertical profile measurements, satellite observations, and other special purpose networks. Section 3 addresses issues associated with maintaining and advancing these programs to assess current and emerging air quality issues. Section 4 provides recommendations related to establishing a standing multi-agency task force for addressing a variety of air monitoring issues and related data gaps that require coordination and/or action.

2.0 Overview of Observation Programs

A variety of measurement programs support air quality assessments. These include routine regulatory and deposition networks, intensive field studies, remote sensing systems, sondes, aircraft campaigns, satellites, and focused, fixed-site special purpose networks. Brief overviews of these systems are provided as a basic inventory to help frame subsequent discussions on strengths, gaps and recommendations. More detailed information is available in the appendices.

Major networks currently operating are emphasized; reference to other networks that have been discontinued, or that were only intended for a specific operating period, is also provided. The focus is on routinely operating North American networks, with limited coverage of European and international efforts relevant to North American assessments.

2.1 Routine surface based ambient air and deposition networks

Routine ambient air and deposition monitoring networks in North America provide over 3000 fixed platforms (figure 2) measuring numerous gaseous species and aerosol properties; see Appendices A and B. Many of these longstanding U.S. networks were catalyzed by the 1970 Clean Air Act (CAA), subsequent CAA amendments, National Ambient Air Quality Standard (NAAQS) reviews, and National Academy of Sciences (NAS) recommendations fostering periodic adjustments to our routine networks. Examples include the Clean Air Status and Trends Network (CASTNET) and National Atmospheric Deposition Program (NADP) addressing acidification; the Photochemical Assessment Measurement Stations (PAMS) in response to persistent ozone pollution, and the $PM_{2.5}$ monitoring networks following promulgation of the 1997 NAAQS. These networks are indirectly supported by extensive meteorological networks (Appendix C).

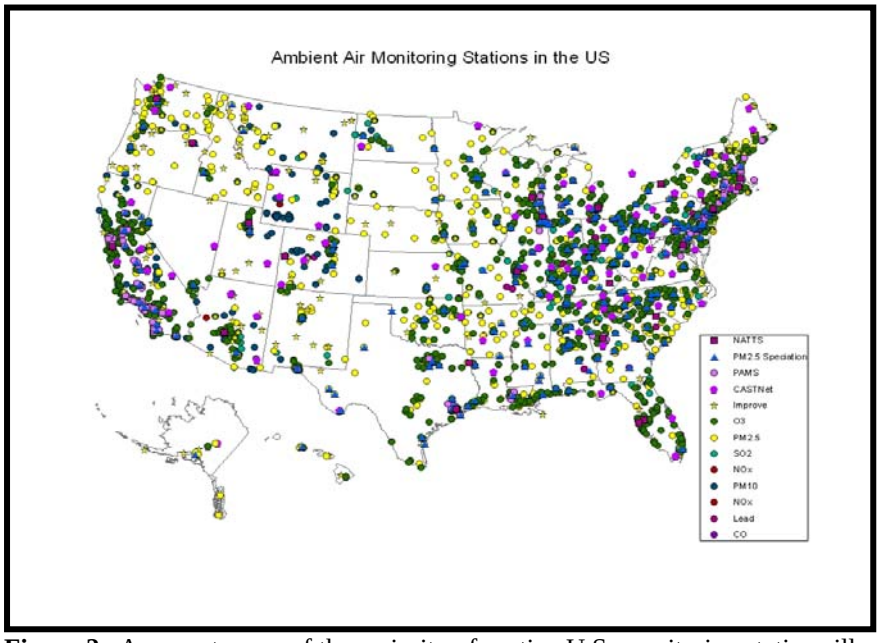

Figure 2. Aggregate map of the majority of routine U.S. monitoring stations illustrating relatively broad coverage across the continental U.S. with noted spatial gaps in low populated areas.

State and Local Air Monitoring Sites (SLAMS). SLAMS is an umbrella term that reflects the ownership and operation of the majority of monitoring stations in the United States by nearly 300 State and local government agencies and Tribes. SLAMS is the principal source of criteria pollutant measurements (ozone, nitrogen dioxide, carbon dioxide, sulfur dioxide, lead, PM10 and PM2.5), each of which has one or more NAAQS with specific concentration levels and averaging periods (http://www.epa.gov/ttn/naaqs/). The extent and composition of these routine networks are strongly influenced by Clean Air Act Amendments (CAAA) and related NAAQS promulgations that provide directed resources, illustrated by the PAMS and PM2.5 network deployments in the early 1990s and 2000s. The National Air Monitoring regulations for U.S. programs are codified in the Code of Federal Regulations (CFR) parts 50, 53 and 58. Funding for these programs is through CAA Section 103 and 105 federal grants to agencies and tribes. States and local agencies are required to match federal Section 105 contributions.

> **Criteria gas networks --** Approximately 3000 surface stations measure some combination of criteria gases, with nearly 1100 stations measuring ozone. Several hundred monitors report concentrations for CO, SO2 and NO/NOx. The majority of these stations are classified as SLAMS, although CASTNET, National Park Service (NPS), PAMS and a variety of special purpose monitors provide additional ozone sites, with CASTNET and NPS providing the majority of rural based ozone platforms.

Photochemical Assessment Measurement Stations (PAMS). Approximately 75 sites in 22 cities were deployed in the early 1990s to measure ozone precursors, largely in response to the 1991 National Research Council study, "Rethinking the Ozone Problem in Urban and Regional Air Pollution." (1991). PAMS and the air toxics networks provide the majority of routinely available non-methane organic carbon (NMOC) measurements. A variety of light, common C2-C10 alkanes, alkenes and aromatics and two carbonyls (formaldehyde and acetaldehyde) are sampled and measured with a combination of continuously operating in-situ gas chromatographs reporting hourly values and canister and cartridge sampling techniques with 3 and 24 hour collection periods, often limited to the ozone season (bounded from April – October). The 1990 CAAA established network design criteria requiring areas classified as serious and above with respect to contemporary (1990-1992) ozone design values to implement PAMS, with minor modifications over the last 25 years. Most VOC sampling sites include instrumentation for ozone and NO/NOx.

Interagency Monitoring of Protected Visual Environments (IMPROVE) Program. IMPROVE has provided nearly a two-decade record of major components (sulfate, nitrate, organic and elemental carbon fractions, and trace metals) of $PM_{2.5}$ aerosols in pristine areas of the United States. Various federal and State agencies support IMPROVE operations at over 100 sites.

SouthEastern Aerosol Research and Characterization (SEARCH) Study. This study experiment is an industry funded network of 8 sites that originally emerged from the Southern Oxidants Study (SOS) in the 1990's and has been operating for nearly a decade.

SEARCH provides an array of standard regulatory compatible measurements but also includes daily chemical speciation at selected time and locations, gaseous ammonia and true nitrogen dioxide – features not available in the major government funded routine networks.

The National Core (NCore) Network. NCore (Scheffe et al., 2009) is a 75 site multiple pollutant component of the routine networks that was fostered by the Ambient Air Monitoring Strategy for State, Local, and Tribal Air Agencies (EPA, 2004) and was promulgated in the 2006 CFR as part of the new monitoring rule (EPA, 2006). NCore is designed to capture urban and regional scale representative concentrations of a variety of trace gases and aerosols to support a range of health effects, model evaluation and research studies. Full deployment is scheduled for 2011.

$PM_{2.5}$, PM_{10} and $PM_{10\text{-}2.5}$ Mass Networks. The 1997 promulgation of a fine PM standard (EPA, 1997) lead to deployment of over 1500 (reduced to about 1000 current day sites) gravimetric Federal Reference Method (FRM) or Equivalent Method (FEM) sites, used for establishing an area's attainment status with respect to the NAAQS, that sample over a 24-hour period with a frequency of daily, every third or every sixth day. Nearly 300 additional gravimetric measurements not meeting FRM/FEM specifications are provided by the chemical speciation sites. Approximately 600 stations provide in-situ estimates of continuous (hourly resolution) $PM_{2.5}$ mass using a variety of measurement techniques. To date, continuous $PM_{2.5}$ mass measurements have not been granted equivalency status although the revised monitoring regulations issued in 2006 (EPA, 2006) provided new approaches for demonstrating equivalency intended to enable broader deployment of these methods. Approximately 1000 PM_{10} gravimetric (24-hr sampling period, typically collected every 6^{th} day) samplers remain in operation. Although a $PM_{10\text{-}2.5}$ standard has not been promulgated, EPA developed a $PM_{10\text{-}2.5}$ FRM based on mass difference of concurrent PM_{10} and $PM_{2.5}$ measurements. $PM_{10\text{-}2.5}$ measurements are planned for the 75 site NCore network.

$PM_{2.5}$ Chemical Speciation Network. The IMPROVE network reports major aerosol components (sulfate, nitrate, organic and elemental carbon fractions, and trace metals) of $PM_{2.5}$ aerosols in pristine areas of the United States. Over 300 EPA speciation sites were added from 2000 - 2002 in urban areas of the United States to assist assessment efforts related to the $PM_{2.5}$ standard. This coverage (Figure 3) across urban and rural areas has been a widely used resource across disciplines (exposure/epidemiological, atmospheric science communities), organizations (academia, industry, government agencies) and several spatial scales of interest (long range hemispheric transport to near source). The speciation networks typically collect a 24 hour sample every three, and sometimes six, days. Daily, 24 hour speciation collection often requested by health effects researchers is limited to less than five sites in Canadian and SEARCH networks. Similarly, only a handful of sites provide near continuous speciation data, usually limited to some combination of sulfate, carbon (organic and elemental splits) and nitrate; enabling insight into diurnal patterns for diagnosing various cause-effect phenomena related to emissions characterization, source attribution analysis and model evaluation. In addition, the

National Air Toxics Trends Stations (NATTS) include aethalometers measuring semi-continuous light absorption, often used as a surrogate for elemental carbon.

The PM supersites program (Solomon et al., 2008) provided highly resolved aerosol measurements at eight U.S. cities for a mix of time periods from 1999 through 2004. Depending on location and time period, a number instrument configurations were deployed ranging from additional spatial coverage of standard speciation sites to systems capturing near continuous size distributed chemical composition profiles.

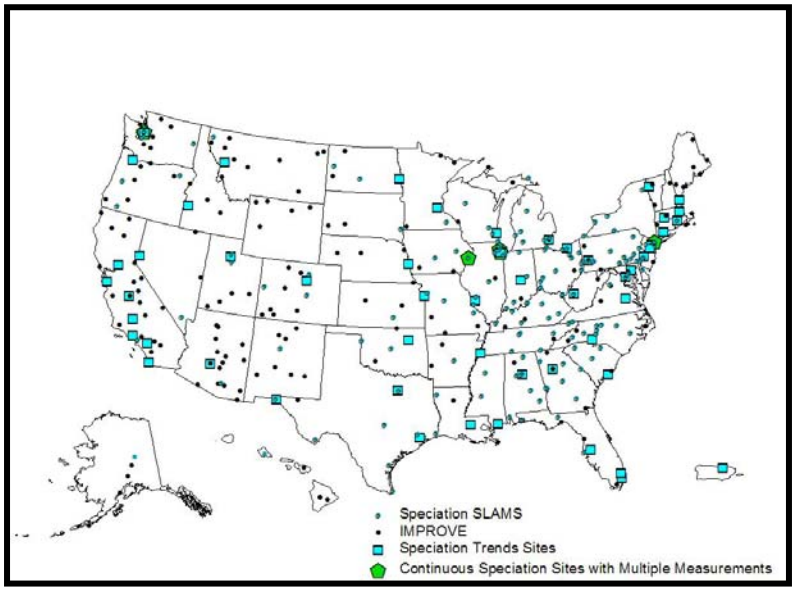

Figure 3. Locations of chemical speciation sites delineated by program type.

Air Toxics Monitoring Program. State and local agencies have measured a variety of metallic and gaseous hazardous air pollutants (HAPs) at over 200 locations since the 1980's. Broad access and use of those data were compromised by a lack of centralized data bases and multiple sampling and laboratory protocols creating data quality consistency concerns. In response to this gap in accessible and centralized HAPs observations, the National Air Toxics Trends (NATTS) network was initiated in 2001 with planned expansion to 28 sites. The sampling protocol has typically been every sixth day for 24 hours.

Among the priority ranked 33 air toxics of US concern, observations of benzene and other common aromatics are fairly widespread and relatively reliable. However, other potentially important species are less well represented in air monitoring. During the initial start-up of the NATTS, six priority HAPs (formaldehyde, benzene, 1, 3-butadiene, hexavalent chromium, acrolein and arsenic) were targeted for inclusion based on results of the 1996 National Air Toxics Assessment (http://www.epa.gov/ttn/atw/nata/). Based on efficiencies in methodologies and the 1999 NATA, NATTS observations expanded to include: acrolein, perchloroethylene, benzene, carbon tetrachloride , chloroform, trichloroethylene, 1,3-butadiene, 1,2-dichloropropane, dichloromethane,

tetrachloroethylene, vinyl chloride, formaldehyde, acetaldehyde, nickel compounds (PM10), arsenic compounds (PM10), cadmium compounds (PM10), manganese compounds (PM10), beryllium (PM10), lead (PM10), hexavalent chromium (TSP), and benzo(a)pyrene.

> **Metals --** Chemical speciation networks provide scans of trace metals through x-ray fluorescence (XRF). Limited to the $PM_{2.5}$ size cut, those data typically are used as indicators grouped with other metals to support source attribution analyses. The majority of metals data are collected through air toxics measurement programs which typically collect total suspended particles (TSP) or a PM_{10} fraction for subsequent metals analysis using inductively coupled plasma mass spectrometry (ICP-MS). Emphasis is placed on high risk related metals such as arsenic, cadmium, chrome, and lead; although data on a variety of other metals often are reported. Hexavalent chromium is required as part of the NATTS and is collected on coated filters and analyzed via ion chromatography. The Integrated Atmospheric Deposition Network (IADN) program, discussed below, analyses for selected metals (As, Pb, Cd, Se).

Clean Air Status and Trends Network (CASTNET). The Clean Air Status and Trends Network (CASTNET) was established in the early 1990s to track changes in dry deposition of major inorganic ions and gaseous precursors associated with the CAA Title 4 reductions in sulfur and nitrogen, designed to address surface water acidification in Eastern North America. Complementing ongoing precipitation measurements from the National Atmospheric Deposition Program (NADP), CASTNET has provided a valuable source of model evaluation data for many of the large regional scale applications since the 1990's. The network of over 80 sites has expanded from an Eastern U.S. focus to cover large areas in the West. CASTNET provides weekly averaged measurements of major ions (SO4, NO3, CA, Na, K, NH4, Mg) integrated over all aerosol sizes are collected through open face filter packs. A subset of sites includes ozone and IMPROVE $PM_{2.5}$ speciation instruments. CASTNET site locations were designed to reflect regional scale air mass samples, relatively free from local urban source signals.

Precipitation based networks: NADP and IADN. Precipitation chemistry is the primary link between atmospheric and terrestrial and aquatic systems. The National Atmospheric Deposition Program (NADP, http://nadp.sws.uiuc.edu/) oversees a network of over 250 sites that analyze for most major ions key to aquatic chemistry characterization utilized in most watershed models addressing acidification and eutrophication effects. The NADP includes the Mercury Deposition Network (MDN, over 90 sites) and a seven-site Atmospheric Integrated Research Monitoring Network (AIRMoN), providing greater temporal resolution.

The joint Canadian-U.S. Integrated Atmospheric Deposition Network (IADN, http://www.msc-smc.ec.gc.ca/iadn/index_e.html) includes a mix of master and satellite stations across the Great Lakes that sample both precipitation and ambient air for a range of toxics compounds. IADN emphasizes many of the more persistent organic

compounds including PCBs, pesticides and dioxins and toxics metals (lead, cadmium, arsenic and selenium).

Other air monitoring networks. For completeness, European air monitoring networks and national/international networks for monitoring persistent organic pollutants (POPs) are listed respectively in Appendices D and E.

Accessing surface network data. Access to routine measurements is available through:

- EPA's Air Quality System (http://www.epa.gov/ttn/airs/airsaqs/) and related DataMart (http://www.epa.gov/ttn/airs/aqsdatamart/) which house criteria gas, PAMS, PM mass, PM speciation and air toxics data.
- EPA's AIRNow (http://airnow.gov/) and AIRNowtech (http://www.airnowtech.org/) provides near real time access to ozone and continuous $PM_{2.5}$ mass data.
- Visualization Information Exchange Web System (VIEWS - http://vista.cira.colostate.edu/views/) developed by the Regional Planning Organizations (RPOs) in support of visibility assessments houses IMPROVE and EPA PM2.5 speciation data.
- CASTNET (http://www.epa.gov/castnet/), NADP (http://nadp.sws.uiuc.edu/) and IADN (http://www.msc-smc.ec.gc.ca/iadn/index_e.html) provide direct access to network data.
- Health Effects Institute (HEI) air quality data base provides access to and analysis tools for processed $PM_{2.5}$ chemical speciation data (http://hei.aer.com/aboutDatabase.php).
- Supersites Integrated Relational Database (SIRD) is described at http://www.epa.gov/ttn/amtic/ssdatamg.html .
- SouthEastern Aerosol Research and Characterization (SEARCH) Study is described and the availability of data is identified at http://www.atmospheric-research.com/studies/SEARCH/index.html .

2.2 Intensive field campaigns

Intensive field campaigns (see Appendix F) of relatively short duration supplement routine longer term monitoring networks by enhancing spatial, temporal and compositional distribution of atmospheric species to better elucidate physical/chemical processes relevant to the fate, transport and removal of secondarily formed gases and aerosols. Typically, these campaigns utilize some combination of aircraft studies, high time-resolved instrumentation and advanced analytical methods (in-situ and laboratory) all complementing routine ground based measurements, which usually do not address reactive gaseous species, aerosol size distributions, organic chemistry characterization and vertically stratified data.

There has been a long history of intensive field campaigns starting with the Regional Air Pollution Study (RAPS) in the 1970's which formed the basis for evaluating the early photochemical gridded Eulerian airshed models used in acid deposition (Regional Acid

Deposition Model) and ozone (Urban Airshed Model) assessments. Landmark campaigns in the United States through the 1980's and 1990's such as the Southern California Air Quality Study, the San Joaquin Valley Air Quality Study (SJAQS)/Atmospheric Utility Signatures, Predictions, and Experiments (AUSPEX) and the Southern Oxidant Study were reviewed as part of the 2000 NARSTO ozone assessment (Solomon et al, 2000). Over the last decade there have been a series of field campaigns focusing on characterization of surface level aerosols through the PM Supersites program (Solomon et al., 2008).

While the early campaigns focused on urban environments, the Eulerian Model Evaluation Field Study (EMEFS) and SOS during the early 1990s shifted focus toward regional spatial scales consistent with the dominant air pollution concerns (acid rain and ozone) of the time. In addition to addressing urban areas of concern such as Houston, TX and Los Angeles, CA, more recent campaigns have extended spatial scales beyond regional studies to address oceanic transport and a variety of air pollution issues across the Northern Hemisphere, recognizing the importance of far ranging source regions and continental scale atmospheric processes. Some of these campaigns include: (1) local and regional studies for the northeast and southeast U.S., portions of Texas, and central and southern California; and (2) intercontinental studies for transport across Atlantic, Pacific, and Indian Ocean areas. A variety of federal (especially NOAA and NASA) and State entities have served as lead agencies for these studies. The appendix provides a listing of studies and summaries conducted since the late-1990s with well known campaigns as far back as the 1990s identified in footnotes. Earlier 20th century historical studies are not addressed.

During the last decade, notable campaigns include a series of regional-intercontinental transport studies, Texas based campaigns, and the $PM_{2.5}$ Supersites program. The International Consortium for Atmospheric Research on Transport and Transformation (ICARTT - http://www.esrl.noaa.gov/csd/ICARTT/index.shtml) served as an organizing umbrella for North American and European field campaigns addressing regional scale processes in the North Atlantic regions of both continents as well as trans-Atlantic transport phenomena. The North American studies included the Intercontinental Chemical Transport Experiment - North America (INTEX-NA) and the New England Air Quality Study - Intercontinental Transport and Chemical Transformation (NEAQS - ITCT 2004) programs, respectively. These ICARRT campaigns provided insights into trans-Atlantic processing of ozone precursors, lightning generated NOx emissions, secondary organic aerosol processes, and biomass burning based on a variety of remote satellite data and in-situ aircraft measurements. The ICARRT campaigns were preceded by the North American Regional Experiment (NARE) in the mid to late 1990's that advanced understanding of the synoptic scale transport features of the North Atlantic region (Stohl and Trickl, 1999; Stohl et al, 2001). The TRAnsport and Chemical Evolution over the Pacific (http://www-gte.larc.nasa.gov/trace/tracep.html - TRACEP) campaigns of 2000-2001 catalyzed much of our current understanding of Asian outflow to North America. Most of the large intercontinental scale field campaigns are considered key parts of the International Global Atmospheric Chemistry (IGAC, http://www.igac.noaa.gov/) program. Findings specific to Northern Hemisphere transport

(Keating and Zuber, 2007) have been synthesized by the Hemispheric Transport of Air Pollution (HTAP) task force.

The Texas Air Quality studies (http://www.esrl.noaa.gov/csd/2006/ - TexAQS and TexAQS II) during 2000 and 2006 are the modern day U.S. regional-urban air quality intensive programs designed to address some of the unique VOC chemistry and transport features of southeastern Texas. The 2006 program extended the earlier study to address climate-air quality linkages and probe further nighttime NOx chemistry.

The $PM_{2.5}$ Supersites program complemented deployment of the routine $PM_{2.5}$ routine monitoring program by providing research grade instrumentation for highly time-resolved data on multiple aerosol physical and chemical properties in major U.S. cities (Atlanta, Baltimore, Fresno, Houston, Los Angeles, Pittsburgh, St. Louis and New York). These data sets spanning 1999 – 2005 were intended to address three primary objectives: monitoring methods development and transfer to operational agencies, support for health effects research, and State Implementation Plan (SIP) development. Several findings are synthesized in dedicated special journal issues (Pandis et al., 2005; Geller and Solomon, 2006; Solomon et al., 2008).

The scheduled 2010 CalNex (http://www.esrl.noaa.gov/csd/calnex/whitepaper.pdf) campaign will build on existing California programs and is intended to address air quality and climate linkages.

2.3 Satellite–based air quality observing systems

An extensive array of satellite-based systems (see Appendix G) with the capability of measuring atmospheric column total species has been established by United States and European Satellite programs lead by the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) in the United States and the European Space Agency (ESA). A suite of satellites including Aqua, Aura, CALIPSO, OCO, Glory, as well as NOAA-17, NOAA-18 and NPOESS, have either been launched since about the year 2000 or have other near-term proposed launch dates. Collectively, they provide remote sensing techniques for measuring columns and/or profiles of aerosols (AOD), O_3, CO, CO_2, CH_4, SO_2, nitrogen oxides, CFCs, other pollutants, and atmospheric parameters such as temperature and H_2O. Most of these satellites have a near-polar low Earth orbit (LEO) allowing for two passes per day over a given location. When taken together, a group of seven of these satellites (Aqua, Aura, CALIPSO, with OCO (failed) and Glory planned for addition in 2009, as well as CloudSat and PARASOL) coined the A-Train, is being configured to fly in a formation that crosses the equator a few minutes apart at around 1:30 local time to give a comprehensive picture of earth weather, climate and atmospheric conditions.

Satellite data effectively complement surface networks and aircraft campaigns and are valuable model evaluation and emissions inventory improvement tools. However, the use of satellite data for air quality forecasting, management, health effects studies and climate change assessments is a fairly complex and misunderstood topic. While satellite

imagery offers the potential to cover broad spatial areas and several pollutants of interest, there are basic incommensurabilities associated with using a space platform designed to effectively probe the upper levels of the atmosphere far from the surface where most air quality issues of interest reside. An understanding of the spatial, temporal and measurement limitations is useful in gauging how these systems complement ground based networks and support air quality management assessments.

Satellite attributes – temporal and spatial coverage, species.

Temporal characterization -- The near polar orbiting tracks of most LEO satellites performing trace gas measurements provide wide spatial coverage of reasonable horizontal (10-50 km) resolution, but deliver only twice daily snapshots of a particular species. In addition, for polar orbits it must be noted that measurements of some species (e.g., those based on UV-visible sensors) can only be taken during the daytime overpass; this further limits the measurements to once daily. Consequently, temporal patterns of pollutants as well as a time-integrated measures of pollutant concentrations cannot be delineated explicitly through satellite measurements alone. However, the geostationary satellite platforms, such as the GOES systems in NOAA, do provide near continuous coverage of physical parameters for weather tracking and forecasting purposes.

For the future, there are proposed campaigns within NASA and across partnership Federal agencies to deploy additional satellite platforms (at least one of which is geostationary) with measurement capabilities for trace gases and aerosols to enhance the space-based characterization of tropospheric air quality (NRC, 2007 and Fishman et al., 2008). More specifically, the National Research Council (NRC) has recommended that NASA implement a set of 15 missions that are phased over the next decade, in addition to implementing the re-baselined NPOESS and GOES program. These "Decadal Survey Missions" include: (1) "Geostationary Coastal and Air Pollution Events" (GEO-CAPE)[1] – to be launched in the 2013 – 2016 timeframe – which is to be at least partially focused on support for air quality assessments and forecasts through the measurement of atmospheric gas columns from a geostationary spacecraft with a frequency less than 1-hr; and (2) "Global Atmospheric Composition Mission" (GACM) – to be launched in the 2016 – 2020 timeframe – which, similar to Aura (sun-synchronous, low Earth orbit), is to be focused on ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction. More detail on the proposed missions and their relationship to chemical constituents of the atmosphere is provided in Appendix G.

Spatial characterization -- Polar orbiting satellites typically provide horizontal spatial resolution between 10 and 100km, depending on the angle of a particular swath segment. Spatial resolution less than 10km is possible with geostationary platforms. Characterization of elevated pollutants, delivered by satellite systems,

[1] GEO-CAPE was originally proposed to the NRC as Geostationary Observatory for Tropospheric Air Chemistry (GeoTRACE) with a similar focus to GEO-CAPE (Fishman et al., 2005).

complements ground based in-situ measurement networks – especially considering that a considerable fraction of pollutant mass resides well above Earth's surface. With few exceptions, satellite data typically represent a total atmospheric column estimate. For certain important trace gases (e.g., NO_2, SO_2, HCHO) and aerosols, the majority of mass resides in the boundary layer of the lower troposphere, enabling associations linking column data to surface concentrations or emissions fields. For example, reasonable correlations (Engel-Cox et al., 2004), especially in the Eastern United States, have been developed between concentrations from ground level $PM_{2.5}$ stations and aerosol optical depths (AOD) from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Aqua and Terra satellites. The Infusing Satellite Data into Environmental Applications (http://www.star.nesdis.noaa.gov/smcd/spb/aq/, IDEA) site provides daily displays and interpretations of MODIS and surface air quality data. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite provides some ability to resolve aerosol vertical gradients.

In contrast to aerosols, most ozone resides in the stratosphere. Various techniques have been developed to extract the stratospheric signal to yield a tropospheric ozone residual (TOR), based on known homogeneities in the stratosphere and the use of chemical transport models and multiple measurements. Early approaches (Fishman, 1978) before and during the Total Ozone Mapping Spectrometer (TOMS) studies combined LIMB (angled view to characterize stratosphere) and NADIR (downward view, characterizing total column) techniques to derive tropospheric ozone residuals. The 2004 launch of NASA's Aura mission with multiple ozone sensors is starting to produce more refined tropospheric ozone maps. However, delineating boundary layer ozone from free tropospheric reservoirs continues to pose significant interpretation challenges.

Measurement issues -- Most satellite air quality observations are based on spectroscopic techniques typically using reflected solar radiation as a broad source of UV through IR electromagnetic radiation (LIDAR aboard CALIPSO does utilize an active laser as the radiation source). While the science of satellite based measurements of trace gases and aerosols is relatively mature, interferences related to surface reflections, cloud attenuation and overlapping spectra of nearby species require adequate filtering and treatment in processing remote signals. For example, aerosol events occurring at the same time as clouds or smoke due to fires may be screened out in applications involving AOD characterizations through MODIS. Correlations between AOD and surface aerosols generally are better in the Eastern U.S. relative to the West due to excessive surface light scattering from relatively barren land surfaces. Also, it should be noted that satellite sensors sum over the entire column of air from ground to satellite, while the interest may only be in concentrations near the surface where people live. Limitations of satellite data are further enumerated and elaborated for the GOME sensors (O_3, NO_2, HCHO), as an example, by the Coordinating Research Council, Inc. (Vijayaraghavan, et al., 2007).

Use of satellite data in air quality management assessments. In broad terms, satellite measurements with few exceptions serve as complements to other surface based and aircraft measurement programs and air quality models. Recent articles on the general use of satellite data for surface based air quality are provided by Fishman et al. (2008) Vijayaraghavan et al. (2007). Satellite applications for air quality forecasting and assessments are covered extensively in the published literature. The following comments are not intended to capture the breadth of applications, but are an attempt to provide a simple description of how satellite observations are most effectively incorporated in air quality assessments. Opinions vary and confusion exists regarding the relevancy of satellite observations for surface based air quality applications. Three general methods are applied in the use of satellite observations in air quality assessments:

(1) Building visual conceptual pictures, e.g. evidence of regional and long-range transport. Satellites support hemispheric and global scale air quality assessments, which are projected to be of increasing importance to North American air quality as both the relative contribution of transported air pollution and air quality-climate interactions increase over the next few decades. The gradual lowering of air quality standards, for example the 2006 revision of the daily $PM_{2.5}$ NAAQS from 65 to 35µg/m3, will increase the relative contribution of trans-oceanic dust to violations. Direct observational evidence of long distance transport clearly can be viewed with satellite imagery (Figures 4 and 5).

(2) Characterizing emissions and air quality model support. Satellite observations play an important role in emissions characterization, particularly for source regions and sectors that have inadequate bottom-up inventories. Satellite NO_2 signals are processed to characterize sources emitting nitrogen oxides. Applications include improving poorly-characterized, expanding emission regions in Asia and India and improving "natural" sources such as lightning and soil NOx. Biogenic VOC emission estimates have been developed (Millet et al., 2008) through processing of satellite formaldehyde signals, using formaldehyde as a reaction product indicator of directly emitted isoprene. The location and source strength of wildfire plumes detected through light scattering and infrared sensors are processed and included as an important component of annual emissions inventory processing (Martin et al, 2006-placeholder) used in driving EPA air quality models such as CMAQ. Sustained satellite observations support accountability analyses addressing the relative efficacy of implemented programs. Due to a lack of surface based true NO_2 measurements, satellite observations have been found to be the most useful ambient indicators of progress in the NOx SIP Call (Kim et al., 2006; Figure 6) and clearly illustrate weekend/weekday oscillations in regional and urban scale NOx emissions.

The role of satellite data in improving emissions supports long range air pollutant transport and background concentration assessments relying on

global scale models, as well as subsequent regional model applications driven by global scale modeling boundary conditions (e.g., most contemporary air quality policy and rule assessments; air quality forecasting). Satellite-based enhancements to surface monitoring networks become more important as air quality assessments increase in complexity by embracing more pollutant categories multiple spatial scales of concern. The reason for this anticipated reliance on satellites is related to the increased role of air quality models for complex environmental characterizations that can not be achieved through observations only. In addition to improving emissions inputs, satellite observations are used to evaluate total column estimates derived from models, which can result in a modification of the underlying emissions inputs or meteorological processes controlling mixing.

(3) ***Surrogates for filling gaps in surface networks.*** Satellite technologies combined with partnerships of Federal agencies such as NASA and NOAA are assisting the air quality community by providing data that covers broad spatial regimes in areas lacking ground based monitors and, more importantly, a vertical compliment to surface based networks. Although 'breathing-zone' monitoring is a rich data source, most pollutant mass resides beyond the representative reach of surface stations. However, during well-mixed afternoon conditions with stable pressure systems, pollutant levels aloft often correlate well with surface conditions, offering potential for "gap filling" in the surface-based networks (Figure 7). However, the appeal of using satellite observations to fill in surface measurement gaps should be tempered with an understanding of the limitations discussed above, for space based measurements, in adequately characterizing near surface conditions. NASA's Aura (http://www.nasa.gov/mission_pages/aura/spacecraft/index.html) satellite, launched in 2004, deploys sensors theoretically capable of measuring all criteria gases, methane, formaldehyde, nitric acid, nitrous oxide, water vapor, radicals (hydroxyl and hydroperoxy) and aerosols – a multiple pollutant, space-based complement to the NCore multiple pollutant, ground-based network and intensive field campaigns. In addition, NASA's Orbiting Carbon Observatory (OCO) was to be dedicated to tracking carbon dioxide levels that currently rely on a complex ground and ocean based network; unfortunately, the satellite did not reach orbit after launch in early 2009.

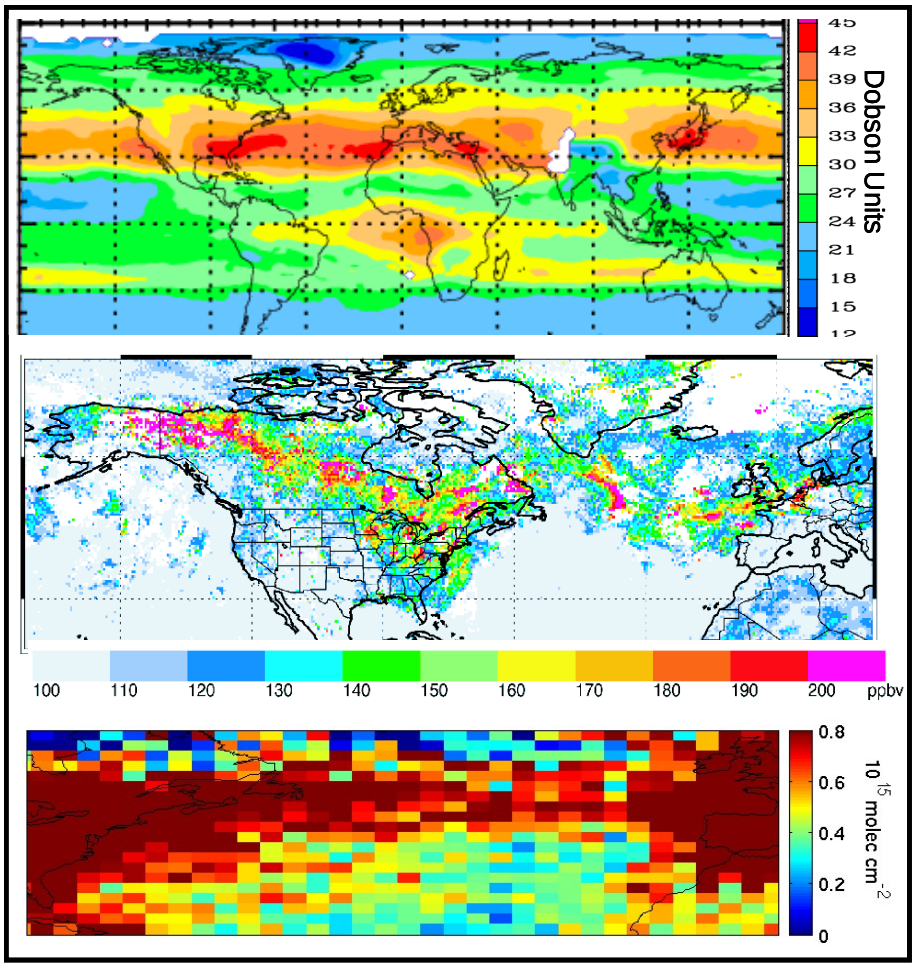

Figure 4. Panels capturing trans-Atlantic transport: top (summer 1997 tropospheric ozone from GOME, Liu et al., 2006); middle (CO column totals from MOPITT for July 2004, Pfister et al., 2005); bottom (Tropospheric NO_2 from SCIAMACHY for summer 2004, Martin et al., 2006).

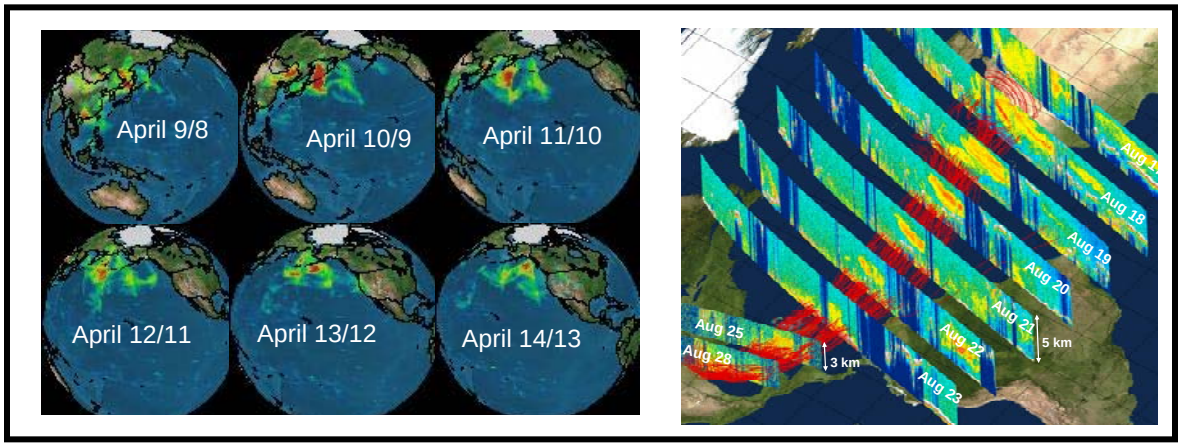

Figure 5. TOMS sequences of well characterized April, 2001 Saharan Dust transport across Pacific (left), and CALIPSO sequences of August, 2006 African dust transport across the Atlantic Ocean (source, Winkler).

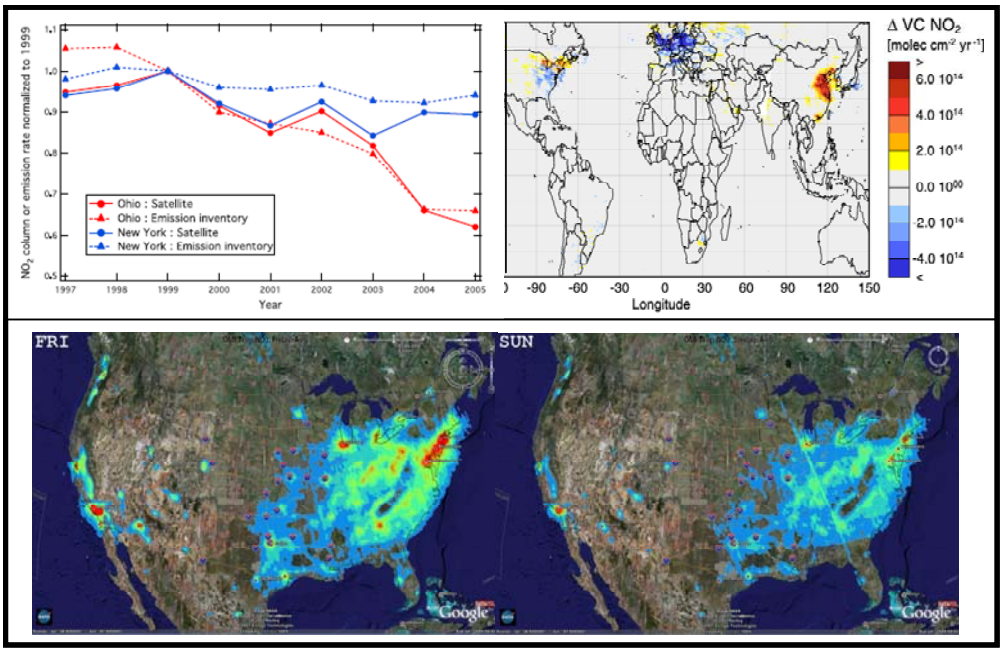

Figure 6. Top Left - superimposed Eastern U.S. emission and combined GOME and SCIAMACHY NO_2 1997-2002 trends (Kim et al., 2006); top right - GOME NO_2 trends from 1995 – 2002 (after Richter, 2005). Clear evidence of reductions in mid-west U.S. and European NOx emissions, and increased NOx generated in Eastern Asia. Bottom: OMI NO_2 column images aggregated for all Fridays (left) and Sundays (right) indicating weekend/weekday patterns associated with reduced Sunday emissions (source, Husar).

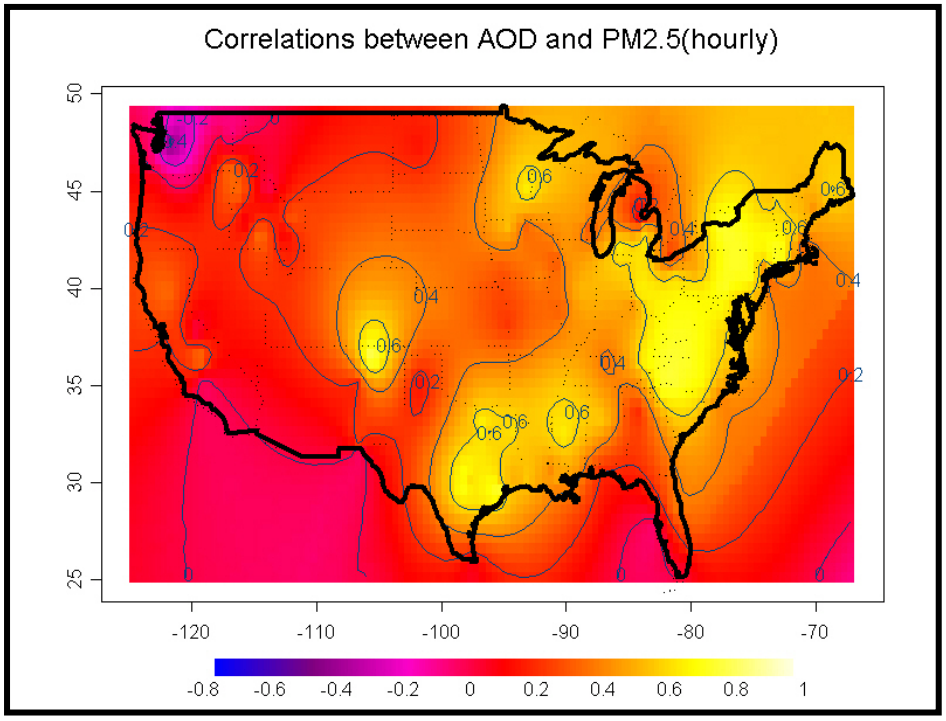

Figure 7. Correlation surfaces between MODIS AOD and hourly PM2.5 surface sites from April - September, 2002 (Engel-Cox, et. al, 2004).

2.4 Observation programs (surface and vertical profile) for climate change, baseline concentrations, stratospheric ozone, and pollutant transport

NOAA and NASA are the lead federal agencies for a variety of observation programs focused on climate change, baseline concentrations, stratospheric ozone, and pollutant transport using both surface-based and vertical profile (including atmospheric columns) measurement networks (see Appendix H). The Department of Energy (DOE) also is actively engaged in observation programs addressing climate impacts. Many of the observation programs supporting these assessment needs rely on partnerships across U.S. Federal agencies, often in collaboration with internationally-based organizations such as the World Meteorological Organization (WMO). The Environmental Protection Agency (EPA), U.S. Department of Agriculture (USDA), U.S. Geological Survey (USGS) and the National Science Foundation (NSF) are key partners that support a variety of overarching research and management programs related to climate change, baseline concentrations, stratospheric ozone, and pollutant transport. This section focuses on the major observational programs and associated monitoring networks in the U.S. that are largely the responsibility of NOAA, NASA and DOE with various levels of participation through partner agencies. The assortment of gases and aerosols which are important climate moderators and/or key air quality indicator and precursor species include CO_2, N_2O, H_2O, CH_4, O_3, CO, aerosols, and halogenated compounds including CFC replacements.

Greenhouse Gas (GHG) Observation systems.

NOAA, NASA and DOE are lead Federal agencies for programs, often in partnership with each other and with international connections, which address greenhouse gas trends, sources, sinks and fluxes across air, terrestrial, and aquatic surfaces. While these programs are focused on carbon dioxide budgets, most important GHGs often are included in other observation programs where feasible. The major U.S. GHG observation programs include:

NOAA global cooperative air sampling network -- Weekly samples from this cooperative network, which includes over 100 remotely located surface stations and a series of ship routes (Figure 8), are used to determine global carbon dioxide, nitrous oxide, methane CFC concentration trends).

AmeriFlux network -- the Department of Energy (DOE) coordinates a multi-federal agency group (with NOAA, USDA, NSF) overseeing the AmeriFlux network of ~90 active sites; see Figure 8 (http://public.ornl.gov/ameriflux/site-select.cfm). The network sites are largely dependent on micrometeorological towers ranging from ~2 meters to 100's of meters in height. Each tower is instrumented with CO2 monitors designed to provide ambient concentration inputs to near ground surface CO_2 flux calculations. AmeriFlux is a component of the larger worldwide Fluxnet system of CO_2 exchange networks that are designed to track storage of carbon in terrestrial systems (http://www.fluxnet.ornl.gov/fluxnet/index.cfm).

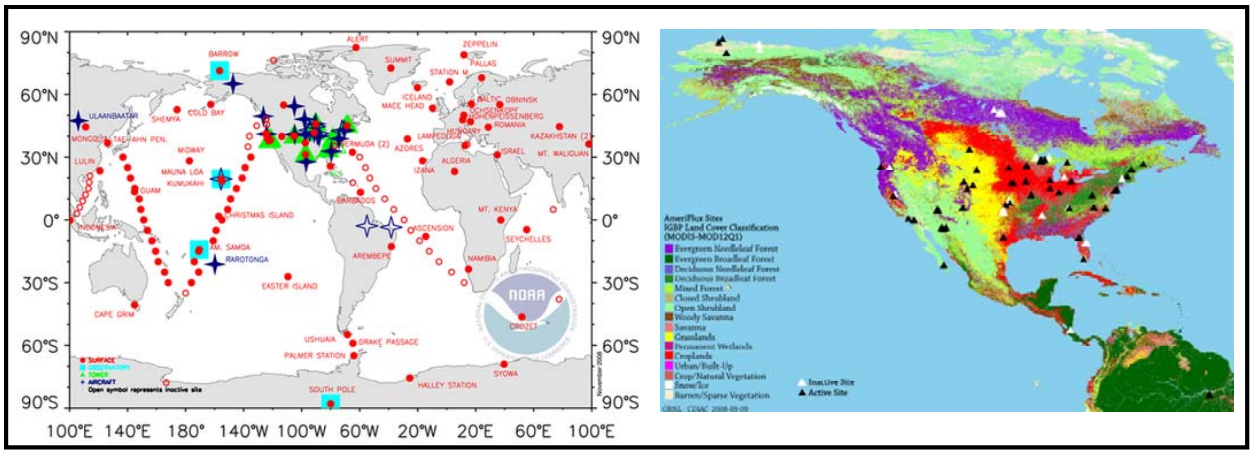

Figure 8. Primary U.S. carbon gas observation programs - (left) Aggregate global map of NOAA climate forcing gas observations (carbon dioxide, carbon monoxide, methane, nitrous oxide, halocarbons) network (http://www.esrl.noaa.gov/gmd/) including routine surface observatories, tall towers, ship routes and aircraft flights that is the basis for tracking global climate forcing gas trends; (right) AmeriFlux carbon flux sites, organized by DOE, designed to estimate carbon exchange across various ecosystems.

Vertical profile (atmospheric column) and satellite observations -- The NOAA network of 8 tall towers (100 – 500 m tall) provides regionally representative boundary layer measurements of near continuous carbon dioxide and related gases. As noted in section 2.3, NASA's Orbiting Carbon Observatory (OCO) satellite mission was scheduled to be launched in 2009 as North America's primary remote sensing platform for carbon and to provide a continental and oceanic scale complement to ground based systems and aircraft programs. In stead, Japan's Greenhouse gases Observing SATellite (GOSAT), also scheduled to be launched in 2009 for CO2 and CH4 observations, will have to provide some of this capability.

Baseline concentration and long range transport programs.

Network of remote (sentinel) surface observation stations -- Remote surface stations strategically located in areas relatively free from nearby sources provide support for characterizing background air quality levels, transport on regional and hemispheric scales and boundary conditions for air quality models. NOAA maintains five baseline sites or surface "sentinel" stations (Mauna Loa; Trinidad Head; Barrow, AK; American Samoa and South Pole) designed to capture long term trends and atmospheric baseline levels in relatively source free environments; these are part of a world wide network of baseline sites coordinated by the WMO (Figure 9). Additional North American locations include Mt. Bachelor, OR; Whiteface Mountain, NY, and ALERT in the Canadian Arctic. In some cases the WMO sites are redundant with sites that are part of the NOAA global air sampling network.

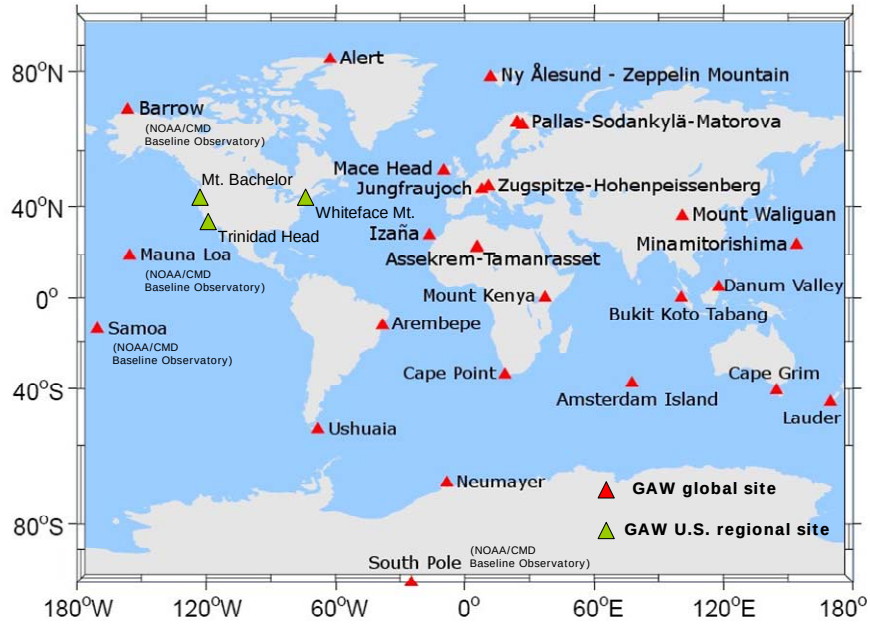

Figure 9 Network of surface based remote observatories organized through the World Meteorological Organization's Global Atmospheric Watch.

NASA fixed site observation networks -- The AGAGE (Advanced Global Atmospheric Gases Experiment - http://cdiac.ornl.gov/ndps/alegage.html), and its predecessors (the Atmospheric Life Experiment, ALE, and the Global Atmospheric Gases Experiment, GAGE) support a variety of climate forcing gases, CFCs and reactive trace gases at remote "sentinel" sites throughout the world.

Surface and aircraft-based air quality measurement programs for vertical profiles. Vertical profiling and total atmospheric column measurements provide important complements to the near surface observations. Elevated observations provide insight into transport phenomena, background levels and are key metrics for model evaluation. The complex near surface deposition and removal processes and micrometeorological processes limit the ability of surface based measurements to characterize conditions aloft, where a significant fraction of air pollutant mass resides. Programs include a variety of aircraft, sondes, remote sensing, tall towers and special field programs largely managed by NOAA, NASA, NSF and DOE. A combination of siting and measurement parameter attributes enable leveraging of observation programs that support assessments addressing climate change, stratospheric ozone, baseline concentrations, and long range transport. These attributes include sampling throughout the atmospheric column (total column and vertically resolved) and, particularly for fixed surface observations, locations in relatively source free locations. While climate and stratospheric ozone depletion assessments benefit from characterizing the full atmospheric column through the stratosphere (~ 35 km), resolution that is specific to the boundary layer (lower 5 km) provided by systems designed to capture the entire atmospheric column often is of marginal value to classic surface-oriented air quality assessments.

NOAA surface and aircraft based air quality measurement programs -- NOAA's Earth System Research Laboratory (ESRL, http://www.esrl.noaa.gov/) conducts a variety of routinely scheduled fixed and aircraft-based measurement programs and a series of intensive special field campaigns providing an observation basis addressing a variety of climate, stratospheric ozone depletion and planetary boundary layer air quality issues – all of which provide a source of data for characterizing conditions aloft. Core elements of these measurement programs include:

- an ozone sonde network (8 sites with 4 U.S. locations) provides one day per week vertical ozone profiles with approximately 100 m resolution from the surface through the stratosphere;

- Dobson ozone spectrometer network (16 station cooperative network) provides near continuous total atmospheric column ozone data;

- routine aircraft flights that characterize vertical distribution of air pollutant species (O3, CO, CH4, CO2, N2O, SF6) relevant to both climate and air quality assessments;

- tall tower sites (8) are part of a larger interagency North American Carbon Program (NACP) which is designed to characterize carbon sources, sinks and removal processes; these towers are currently located throughout the continental United States using television and cell phone transmittal towers (100 – 500 m tall). They provide regionally representative boundary layer measurements of near continuous CO_2, CO, CH_4 and associated fluxes, various trace gases, and meteorological parameters;

- special intensive studies with aircraft focusing on regional U.S. air quality issues typically conducted every two years;

- NASA, often in collaboration with NOAA and other international organizations, participates in a variety of special studies (section 2.2) using aircraft.

These aircraft, sonde and total column measurement programs in combination with NOAA remote surface based measurement observatories (http://www.esrl.noaa.gov/gmd/about/airquality.html) and carbon focused tall tower measurement program (http://www.esrl.noaa.gov/gmd/ccgg/towers/index.html) provide a basis of sustained observations providing long term records of baseline air quality from the surface through the stratosphere. These programs represent a substantial component of the U.S. contribution to a wider international monitoring effort, much of which is organized through the World Meteorological Organization (WMO).

European based aircraft programs: MOZAIC and CARIBE -- The measurement of ozone, water vapor, carbon monoxide and nitrogen oxides aboard Airbus in-service aircraft (MOZAIC http://www.fz-juelich.de/icg/icg-ii/mozaic/home) and Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container (CARIBIC http://www.caribic-atmospheric.com/) programs provide near continuous air quality measurements conducted in commercial European based airlines that include several trans-Atlantic flights to and from North American cities. These programs provide the most extensive routinely-collected, vertically-distributed air quality data throughout the troposphere.

Satellite air quality observation programs -- As noted in Section 2.3, NASA oversees operations of several satellite missions whose objectives are oriented toward both a fundamental understanding of the lower atmosphere to complement and evaluate satellite products, with generally a broader hemispherical or global scale perspective that often overlaps with regionally focused initiatives. NOAA's National Environmental Satellite and Data Information Service (NESDIS - http://www.nesdis.noaa.gov/), also, oversees operations of the nation's geostationary and polar operational satellite programs (GOES and POES) providing imagery for weather forecasting and observations of light scattering relevant to aerosol characterizations.

Selected Meteorological Observation Systems. Two categories of above surface meteorological systems are included here because of their close linkage to air quality assessments. Solar radiation networks provide estimates of atmospheric aerosols and various trace gases, in addition to basic data used in for radiation energy components of transport models. Meteorological systems that enable estimation of the planetary boundary layer are especially important for the near surface air quality analyses and model applications.

Solar radiation networks -- Full spectrum and specific solar radiation wavelength measurements provide important data used for characterizing energy budgets for meteorological models and climate change assessments, atmospheric column aerosol light scattering, and as direct indicators of UV radiation exposures relevant to human, agricultural and ecosystem health. A variety of federal agencies including NOAA, NASA, EPA, USDA and the NPS all have participated in a variety of measurement programs.

The AErosol RObotic NETwork (AERONET) is a collaborative global network of Sun Photometers organized by NASA providing ground based aerosol optical depth (AOD) estimates used primarily to evaluate space-based aerosol measurements. NOAA's Surface Radiation Budget Network (SURFRAD) is part of the global Base Line Surface Radiation (BASR) Network. It is an important surface complement to satellites, and is used for characterizing surface energy balances and supporting a variety of global scale climate models. In addition, the AErosol RObotic NETwork (AERONET) is a collaborative global network of

Sun Photometers organized by NASA providing ground-based AOD estimates used primarily to evaluate space-based aerosol measurements.

The Brewer UV spectrophotometer networks started in 1994 with EPA's UVNet program and included over 20 sites until funding was eliminated in 2004. A subset of six sites supported by EPA and NOAA is operating as the NOAA-EPA Brewer Spectrophotometer UV and Ozone Network (NEUBREW). These UV networks have been motivated by a range of effects ranging from skin cancer to forest and crop productivity. Interest in characterizing association between changes in stratospheric ozone and attenuation of UV reaching the surface has provided some residual EPA funding support. The Brewer instruments are capable of providing total column ozone and SO_2 estimates.

Observations for evaluating PBL heights -- Characterizing the planetary boundary layer (PBL) height (or mixed layer height) is an important physical constraint in air quality models. PBL is a derived quantity based largely on vertical temperature profiles and refractive index structure parameters, Cn^2. The deployment of the NOAA Profiler Network (http://www.profiler.noaa.gov/npn/ - NPN) over the last decade has added a near continuous stream of wind vector data to complement the National Weather Service's (NWS) rawinsonde network which provides twice daily soundings spread across nearly 100 locations throughout the United States. The NPN includes 35 unmanned Doppler radar sites profiling the troposphere (10-15 km), is concentrated in the central United States, and designed for violent weather forecasting. The Photochemical Assessment Measurement Stations (PAMS) program supports ~20 radar profilers that provide highly resolved wind profiles and Cn^2 coefficients of the boundary layer (up to 5 km). The boundary layer radar profilers, especially when complemented by temperature profiles generated by Radio-Acoustic Sounding System (RASS) offer a source of relatively untapped data for model evaluation.

In addition, cloud height measurements through ceilometers are reasonable PBL depth indicators for non-clear sky conditions; a spatially extensive network for broad application is available through the NOAA Automated Surface Observing System (ASOS). In addition, since 2004, over 400 commercial aircraft have been collecting meteorological variables (temperature, pressure, RH, winds) as a part of the tropospheric Airborne Meteorological Data Reporting (TAMDAR - http://www.airdat.com/./tamdar/index.php) system. While TAMDAR is designed to provide near real time data for forecasting, the system provides valuable vertical profile temperature data (and other variables) during ascents and descents that potentially can be synthesized to fill in temporal and spatial gaps of ground based profilers.

The Meteorological Data Ingest System (MADIS - http://madis.noaa.gov/) is an integrated system incorporating observations from a variety of surface based, vertical profile and satellite networks that provides a centralized source of observations servicing evaluation efforts.

3. Maintaining and Advancing Observation Programs

3.1 Opportunities and critical measurement gaps

Enhancements of the temporal, spatial and compositional characterization of air quality will be needed to successfully assess the variety of current and emerging air quality issues described above. Network design is naturally based on the mission objectives of individual agencies; this results in observational gaps that affect broadly integrated environmental assessments. Consequently, a comprehensive multiple organization view of observational systems is necessary to take advantage of existing observation programs and to identify important information gaps that may strengthen the interoperability of networks. Because observations can serve multiple objectives, and disparate organizations share the common need of characterizing the environment, an intrinsic connectivity exists among a variety of measurement programs. Integration opportunities from a variety of perspectives include:

- Enhancing the horizontal and vertical characterization of key species,
    - horizontally by blending urban and rural based networks (e.g., urban-based speciation networks with the rural-based IMPROVE program; SLAMs ozone urban stations complementing CASTNET rural ozone stations),
    - vertically through the atmospheric column by blending of satellite data, surface measurements, and vertically-resolved observations from ground-based and aircraft platforms;
- Combining precipitation and dry observation networks to develop deposition fields, as performed currently through the CASTNET and NADP programs;
- Aligning atmospheric deposition observations with soil and surface water measurement campaigns;
- Collocating a variety of different species measurements to yield multiple pollutant characterizations within a consistent spatial frame;
- Matching ambient observation measurement fields with human activity patterns to estimate exposures; and
- Using air quality models in combination with observations to address spatial and temporal gaps associated with limited observations**.**

When the complex of dimensions inherent in environmental assessments combined with an accounting of available observations are considered, observational improvements would add considerable value to our system of air quality observations.

3.1.1 Measurement gaps of specific species

The following discussion rehashes longstanding observation needs advocated by the scientific community through NAS reports, NARSTO assessments and other venues. To add some context, consider that the U.S. EPA's model evaluation program does not routinely include comparisons between observed and modeled CO, NO, or VOCs. These conservatively acting species are important indicators to evaluate the

emissions, meteorological and basic geometry used and represented in air quality modeling platforms. Without an understanding of the model's performance of conserved species, the assessment of performance of reactive or secondarily formed species, such as ozone, becomes increasingly speculative. Yet, because of a severe shortage of key representative measurements, that is precisely the approach used in most model evaluation efforts (e.g., Appel et al., 2007).

Shortage of VOC measurements in representative areas. Over the last two decades the importance of biogenically generated VOCs (isoprene, terpenes, sesquiterpenes) has been recognized in the formation of ozone and secondarily formed $PM_{2.5}$. Nevertheless, the urban based PAMS network designed in the early 1990s remains the primary source of VOC data in the United States. Additional coverage in U.S. cities is provided by the NATTS air toxics sites. The design of the current VOC networks does allow for associating reasonable urban-based VOC air quality and emissions trends, an initial step in accountability analyses. However, the absence of VOC data in most moderate-sized cities raises concerns regarding the overall representativeness of a network based primarily on the severity of ozone problems in the early 1990s. More troubling is the lack of rural based VOC data, especially formaldehyde which, in addition to being a designated HAP, can provide relational insight into biogenic emissions and provides a useful diagnostic for model evaluations. In addition, formaldehyde could indicate alterations in atmospheric chemistry associated with potential transition to alternative transportation fuels (e.g., grain based and natural gas). Finally, the value of total column formaldehyde from satellites could be enhanced by providing a more spatially rich surface observation complement.

Nitrogen species. Nitrogen plays an important role in a variety of environmental assessments relevant to ozone, aerosols, acidification, eutrophication and visibility. Unfortunately, there are numerous nitrogen observation gaps which is a concern considering that NOx emission reductions have dominated national air program rules (mobile and stationary sources) over the last decade. An adequate observation base does not exist to determine if ambient nitrogen response is consistent with measured and predicted NOx emissions changes. The ability of the existing urban-oriented NOx measurement network to detect ambient NOx changes associated with regional scale EGU emission reductions is compromised by strong local mobile source NOx emission signals. Also, NO_2 data from most network NOx monitors remains compromised by other oxidized nitrogen species, an issue prevalent for nearly two decades. The NCore network will provide a modest contribution by providing for reactive nitrogen (NOy) measurements in over 20 rural locations and, ideally, spur greater coverage and deployment of instruments producing true NO_2 observations. True NO_2 is a useful diagnostic species for atmospheric chemistry processes and serves as a surface based link to satellite NO_2 column data. Despite the availability of relatively reliable, low cost true NO_2 methods, and ongoing reviews of the nitrogen dioxide NAAQS and NOx/SOx secondary standards, EPA has not actively pursued these important enhancements in routine networks

Further resolution of reactive species including peroxy acetyl nitrate (PAN) and nitric acid (HNO3) would elevate our ability to diagnose a number of processes related to deposition and ozone production along transport corridors. An expected increased penetration of grain based fuels potentially would elevate PAN concentrations, and along with other carbonyl observations, PAN would provide a useful accountability indicator associating the impact of new fuels on ambient chemistry.

Reduced nitrogen species, ammonia gas and ammonium ion, are important components of an overall nitrogen mass balance and important components relevant to visibility, fine particles and ecosystem deposition assessments. There is a scarcity of ambient ammonia measurements as most ammonia measurement programs are located in strong source agricultural locations to estimate emissions flux. Ammonium ion is analyzed as part of the chemical speciation program, but ammonia volatilization within the sampler and during filter handling creates a negative bias in those values. Routine measurements at one or two representative locations of nitrate radical (NO_3^-), the dominant nighttime oxidation specie, also would enable diagnosing model behavior relative to overall nitrogen balances as well as secondary aerosol formation.

Nitrous acid, HONO, is an important generator of hydroxyl radicals (Stutz et al., 2004, Zhou et al., 2002), and HONO participates in heterogeneous reactions with aerosols; HONO emission rates and chemistry generally are believed to be poorly characterized in chemical transport models (CTMs).

Although several desired nitrogen species are mentioned, a reasonable priority would include measurement enhancements in true nitrogen dioxide and ammonia to our national networks.

Mercury. Mercury remains one of the more complex atmospheric species with limited laboratory bench level information on atmospheric reaction rates and products. An initial effort organized through the NADP to provide routine dry mercury (elemental and gas and particulate bound) measurements offers centralized quality assurance and data management, an important consideration given complexities associated with mercury measurements. Speciated mercury measurements are important for diagnosing modeling applications and progress tracking of emission reduction strategies associated with the Clean Air Mercury Rule (CAMR -- http://www.epa.gov/camr/).

CO and SO_2. Carbon Monoxide (CO) is a relatively conservative species useful for diagnosing a range of emissions inventory and physical process characterizations in air quality models. Sulfur dioxide (SO_2), as a major component of sulfur budgets used in ecosystem deposition assessments and observations in combination with particulate sulfate, provides a basis for evaluating model derived sulfate production underlying particulate matter mass and visibility estimates. Ambient SO_2 concentrations also are used in parameterization schemes characterizing ammonia deposition in air quality models. The available SO_2 and CO measurements are largely urban-based and often in proximity to major source areas, limiting their representativeness of broader spatial domains. In addition, most of the current instruments were designed to capture high

concentration levels for compliance purposes and do not capture reduced concentrations in well-mixed urban and rural environments.

Organic aerosol composition. The organic carbon fraction of the total aerosol budget will increase given the planned reductions in inorganic gaseous precursors from national mobile source and EGU targeted programs combined with a large pool of uncontrollable natural carbon from fires and biogenic emissions. Chemical speciation networks provide an aggregated total organic carbon estimate, since it is not practical to resolve the full molecular spectrum of organic aerosols. Nevertheless, key molecular markers would assist a variety of source apportionment applications and analyses delineating primary and secondary, as well as modern and fossil-derived organic fractions. Given the resource burden of sample collection and analysis for organic composition, a modest grouping of sites and sampling frequencies should be considered to supplement or replace current routine analyses.

Aerosol physical properties. Interest in near roadway and ultrafine particle exposures, insight into particle nucleation processes and tracking change in aerosol size distributions associated with fuel transition programs (e.g., Wahlin et al., 2001) continue to raise the need for improved particle property measurements. Recent advances in instrumentation that produce relatively reliable and low cost estimates of particle number and surface area offer potential for routine network operations. Consideration of an initial 2-4 sustained sites to capture long term changes in particle size characteristics are recommended. Particle size measurements could be incorporated in a more focused effort characterizing a range of particle and gaseous attributes associated with near roadway environments.

3.1.2 Spatial scale considerations

Integrated assessments necessarily deal with the behavior of pollutants over multiple spatial scales, owing to the fact that many important physicochemical processes occur on overlapping scales of time and distance. Characterization of regional- to urban-scale pollutant gradients provides insight regarding the relative contribution of regional and local sources to local pollutant levels. Matching actual pollutant exposure to individuals, a key link in the source-to-outcome accountability chain, implies considerably greater demand on fine scale characterization. Primary emitted pollutants, which include most of the designated 188 HAPs as well as a significant fraction of PM, are subject to very dramatic gradients in the near source region which often coincides with high density populations.

Juxtaposed with increased attention to near source/roadway exposures is an emerging understanding of long range transport and a gradual rising of background pollutant levels. The significance of these contributions to North American air quality is magnified given the progress in North American pollution abatement relative to increased atmospheric loading from expanding economies in Asia and India. Compounding the relative influence of transport and a rising background is the adoption of gradually more stringent U.S. air quality standards. Consequently, the adequacy of observations that enable characterization of pollutant inflow and outflow to and from North American borders, as

well as the global observation capability of tracking "background" levels is relevant to North American multi-pollutant air quality management and accountability progress. Noted spatial gaps in our observation networks include:

Internal rural coverage. Three national level networks form the backbone of rural air quality measurements: IMPROVE, CASTNET and the NADP. While these networks were designed for specific objectives, they have been extremely useful for air quality model evaluation and transport assessments, data uses outside the primary design objectives of these programs. However, analysts use whatever data are available, and one should not assume that adequate horizontal spatial coverage of important species exist across the United States. Major gaps exist in surface-based ozone and key source indicator and precursor species (CO, SO2, VOCs, speciated aerosol, NOx and NOy) throughout the midsection of the nation (See Figure 2 in Section 2). EPA's primary NAAQS which address human health effects have played a dominant role in driving the urban-oriented coverage for these important species. In addition to the concerns related to increased importance of background levels, the gradual increase in stringency of primary NAAQS (e.g., lowering the ozone standard from 0.84 to 0.75 ppb) will increase attention to adequacy of observations covering rural-based populations. In parallel, there have been and are expected to continue increased efforts in promulgating secondary standards that do not default to primary standard metrics, a common practice over the last two decades. For example, inclusion of ecosystem based critical load concepts into the formulation of a combined NOx/SOx secondary standard targeting acid deposition and eutrophication is being pursued by the U.S. EPA.

Sentinel stations to link transport regimes. Although sentinel stations were included in the inventory of networks discussed above, the addition of 2-3 well placed remote stations (e.g., East and West North American Coast) would provide valuable support for a range of trans-oceanic transport assessments, global and regional air quality model evaluation, boundary condition estimates and insight into trends of background air quality levels. All sentinel sites need to be supported by a stable resource base, since their benefit is often derived from analyzing long term trends. Over the past decade key sites in the Pacific Northwest have been supported by a series of research grants and supplementary government funding. Coincident measurements of O_3 and aerosol components (nitrate, sulfate, organic and elemental carbon, trace metals), precursors of O_3 and aerosol (total reactive nitrogen, peroxyacetyl nitrate, and VOCs, sulfur dioxide) and atmospheric tracers (such as carbon monoxide and carbon dioxide and mercury) will strengthen long-range transport assessments and model evaluation efforts.

Total atmospheric column characterization through satellites. Satellite platforms provide total atmospheric column estimates of important atmospheric species. Based on the historical reliance on ground based point measurements, there has been some confusion within the air quality management community with regard to the utility of satellite observations. Some of this confusion is related to a perception that satellite observations may be able to replace surface measurements. It is important to reinforce the understanding that satellite measurements are a critical data element that facilitates the integration of global scale air quality models into the existing regional scale focused

air quality modeling framework to assist in important policy relevant assessments related to characterizing background and hemispherical air pollution transport contributions to regional and urban zones of interest. More generally, the gradual evolution of more complex air quality assessments that incorporate multiple spatial scales and pollutant species out of necessity will rely more heavily on air quality model systems. In this area, the contribution of satellite data will be realized mainly as a key model evaluation component for total atmospheric column loadings and for inverse modeling of data poor areas of emissions.

Secondarily, satellites will continue to provide useful illustrations of episodic events associated with fire and dust generation and transport, as well as supplementary sources for identifying air pollution trends across very extensive spatial zones (e.g., broad view of global change in NOx emissions distribution). Polar orbiting satellites provide extensive spatial coverage but afford limited temporal resolution as each orbiting platform is limited to two swaths per day. In response to the NRC's decadal survey on Earth Science and Applications from Space, the interagency Geo-CAPE proposal (NRC, 2007 and Fishman et. al, 2008) calls for deployment of geostationary platforms focused on North America providing near continuous streams of chemical information comparable to that provided by NOAA's GOES (http://www.oso.noaa.gov/goes/index.htm) platforms, widely used for observing weather systems and meteorological forecasting. Agencies with strong interests in boundary layer characterizations (e.g., EPA) should consider sponsoring satellite missions and other atmospheric column characterization campaigns so that operational designs are matched efficiently with program objectives. The Landsat program (jointly managed by the National Aeronautics and Space Administration (NASA) and the U. S. Geological Survey (USGS)) illustrates the successful partnering of an agency focused on surface resources using satellite data to better resolve surface information.

The anticipated deployment of geostationary air quality satellite missions in the next decade will provide a near continuous stream of air quality information for North America, and strongly influence design of our routine monitoring programs and perhaps elevate near term air quality characterizations equivalent to weather forecasting. Technology development for these new generation platforms to allow better characterization of boundary layer air quality is encouraged. Although satellites offer potential to enhance air quality assessments, considerably greater value would be derived from satellite observations through complimentary ground-based point and vertical profile observation programs to fully connect and evaluate observations throughout the vertical extent of the atmosphere. Leveraging satellite air quality missions will enhance both regional and global scale air quality characterizations, addressing important criteria pollutants such as ozone and PM2.5 and selected air toxics such as formaldehyde.

Several of the surface based recommendations for trace gas measurements of true formaldehyde, NO2, CO and SO2 discussed above are intended to leverage satellite information. Perhaps more important is a very definitive expression of support and commitment from the client community (EPA, State and local air pollution agencies, regional planning organizations) on engaging in the use of satellite products. For

example, the ability to secure funding for NASA's Geostationary Coastal and Air Pollution Events (*GEO-CAPE*) geostationary air quality mission is related to a clear client base that will, over time, demonstrate societal benefits beyond research objectives of such a mission.

Expansion of the use of satellite observations to assess air quality has become increasingly relevant over the last decade. Satellite data allow examination of broad-scale patterns of transport and chemistry, as well as providing top-down constraints on emissions estimates. Use of satellite observations in boundary layer air quality assessments has elevated our conceptual understanding and improved our ability to assess a variety of intra- and inter-continental air pollution transport events associated with ozone, dust and wildfire events. Our understanding of pollutant transport across oceans and associated growth of emissions from emerging Asian economies has relied on satellite-based observations. Lacking an adequate existing ground-based nitrogen gas monitoring network, satellite data provide our only record of changing ambient reactive nitrogen levels associated with major reductions of nitrogen oxide emissions brought about by the NOx SIP Call (2000-2005) in the Eastern United States. Satellite observations also allow for near real-time characterization of fire emissions, a major emissions source equivalent to transportation and energy generating sectors, that benefits air quality forecasting as well as traditional retrospective analyses.

Vertical profiles of key atmospheric species. Vertical profiling of boundary layer and free troposphere air chemistry in North America is limited to specialized field campaigns and a small number of ozone sonde releases. Consideration of more routine boundary layer profiling of meteorology and air chemistry would provide valuable support for model evaluation and to emerging efforts integrating models and observations. This integration is especially relevant as increasing pressure, based on a variety of air quality and deposition characterization demands, will be placed on the technical foundation supporting multi-pollutant air quality management.

For example, inlet systems for surface-based networks typically are positioned in the lower 10 meters of the atmosphere, which is representative of most human breathing zones. However, the lower 10 meters only occasionally represents mixing ratios of the planetary boundary layer which models attempt to characterize. In addition, the rawinsonde network lacks adequate temporal resolution to adequately characterize diurnal development and collapse of PBL heights and NPN does not provide sufficient vertical column resolution for PBL characterizations. Radar profilers are an underutilized resource which has inadequate spatial coverage and lacks a consensus methodology to synthesize raw data into spatial and temporal observation patterns conducive to model evaluation.

From a satellite data perspective, satellite total column data rarely is representative of surface based conditions. Consequently, routine vertical profiles of key species such as ozone, NO2, CO, SO2 and aerosols can effect a linkage between surface-based point and satellite observations, thereby leveraging the value of each system. Adequate characterizations of surface and lower troposphere air quality provide opportunities to

evaluate satellite observations and derive regression relationships to extend use of satellite data to supplement sparsely-monitored areas. Potential investments in vertical profiling programs that conceivably would leverage satellite data include:

- Expansion of NOAA's ozone sonde program to provide added coverage in the continental U.S. and addition of key trace gas measurements.

- A sustained U.S. based aircraft campaign (national and international) similar to the MOZAIC/CARIBE European effort that would produce routine vertical profiles of key trace gases and aerosols;

- Deployment of fixed site LIDARS at key locations throughout North America to provide continuous profiles of back-scattered light serving as a direct link between ground-based AIRNOW $PM_{2.5}$ in-situ samplers and MODIS and CALIPSO satellite instruments. Such a network could build on the existing Regional East Atmospheric Lidar Mesonet (REALM) proposal (Hoff et al., 2003) that includes 13 sites in the U.S. and Canada.

Near source - fine scale characterization. Ambient monitoring networks typically have provided a primary data resource to support a broad range of exposure, epidemiological and risk assessment studies associating health outcomes with pollutant exposure. Epidemiological studies traditionally have used air monitoring data from single, centrally-located urban stations for a surrogate of human exposure. Central to the specification of human exposure and ambient air pollution are the facts that (a) most people in North America live or commute in locations proximate to sources, especially roadways, and (b) pollutant gradients in urban environments create large uncertainties in outdoor exposure characterizations of large city conditions. Neither of these is addressed effectively in current monitoring programs.

3.1.3 Gaps in temporal resolution

A mix of resource, technological and incentive related constraints preclude realization of an idealized observation system that incorporates highly resolved temporal measurements accommodating time periods synchronized with important process features and effects responses. Widely acknowledged gaps in temporal treatment of measurements include lack of daily and sub-daily speciated PM and the limitation of polar orbiting satellites that produce one or two instantaneous readings per day and the twice daily release of weather and ozone sondes.

The perceived need for temporal resolution of PM observations has increased with recent findings regarding human health response (Peters et al., 2001), as well as with our developing understanding of multi-scale atmospheric processes. With the exception of PM mass, particle properties are not monitored continuously on most networks. Routine PM chemical speciation networks acquire 24 hour averaged samples, collected every third or sixth day. This sampling design is adequate for supporting the annual PM2.5 standard and the U.S. regional haze program, but limits the investigation of PM

associations with adverse health effects, evaluation of emissions, development of air quality models, and application of source attribution techniques.

North American networks have deployed over 500 routinely operating continuous $PM_{2.5}$ mass samplers. The use of these sites to characterize particle concentration distributions across broad spatial regimes is complicated by different instrument configurations and, within an instrument class, variable volatility losses in different sampling environments. Efforts to harmonize these measurements through instrument modifications and correlation techniques would advance both the temporal and spatial resolution for mapping $PM_{2.5}$ concentrations.

Recent reduction of the U.S. daily $PM_{2.5}$ standard from 65 to35 $\mu g/m^3$ elevates the importance of continuous instruments that are consistent with reference gravimetric methods. Harmonization with reference methods may catalyze greater use of continuous data, but such harmonization with the current filter-based reference method may detract from efforts to produce "true" atmospheric aerosol measurements. The variety of measurement-induced artifacts (e.g., loss of semi-volatile mass from nitrate and from organics and retained water) associated with filter-based, gravimetric techniques creates significant ambiguity in the PM data. While there remain significant issues regarding data consistency, due partly to a mix of measurement techniques, continuous mass measurements have been well integrated into the networks.

Significantly less use of continuous speciation technologies has occurred in the routine monitoring networks. Exceptions include the Supersite program, and light absorbing aethalometers (an indicator for elemental carbon) in the U.S. air toxics NATTS. Also 10-20 continuous sulfate and organic-carbon analyzers are located in a mix of Canadian, SEARCH and State or local agency platforms.

Several special studies emerged in the late 1990s, which began systemic evaluation of continuous measurements of PM chemical properties, a transition from the emphasis on the oxidant studies conducted during the prior two decades. The $PM_{2.5}$ Supersites program (Pandis et al., 2005; Solomon et al., 2008) spurred the testing and development of a variety of continuous aerosol mass, chemistry, and physical-property measurement technologies. However, there has not been a sustained effort to deploy and maintain semi-continuous particle speciation instruments, with noted exceptions in the SEARCH, Regional Planning Organization (RPO -- http://www.epa.gov/air/visibility/regional.html), and Canadian programs.

Total atmospheric column and vertically resolved profiles of key air quality and meteorological observations typically lack adequate temporal resolution, in addition to a generally sparse spatial distribution, as discussed above. The twice daily weather and ozone sondes often miss key periods of boundary layer evolution important for model evaluation. Polar orbiting satellites typically provide one and sometimes two instantaneous readings per day for a specific location which hinders efforts to integrate space-based measurements with surface systems that typically provide total time averaged or near continuous outputs.

3.2 Barriers to progress

Any approach to addressing the emerging air quality and assessment issues must recognize factors associated with resource, technological and institutional constraints that impede progress in our air quality observation programs.

Sustaining infrastructure. To some degree our observation systems are treated as an entitlement, the information is highly valued, easy access is expected but little if any responsibility with regard to enrichment or sustainability enters the conscious thoughts of most data users, somewhat analogous to attributes of our transportation infrastructure illustrated, for example, by the degradation of numerous highway bridges. Outdated technologies, equipment in disrepair and aging operators typify the basic problems encountered in sustaining operability of many current measurement networks. This situation can be explained partly by recognizing that measurement systems are support vehicles for more visible downstream assessments, and often rely on the trickling down of resources which continues to diminish in resource constrained environments.

Organizational priorities. Organizations typically lack the resource flexibility to support medium or low priority measurement campaigns. For example, the U.S. EPA relies on federal reference and equivalent methods to address compliance issues associated with air quality standards. In times of shrinking budgets, the resource pool for other "linkage" measurement programs of strong scientific value generally are considered a lower priority and not funded. Recent EPA examples include (1) the continued acceptance of existing NOx instruments with known biases despite development of a new NO_2 standard, and (2) expansion of the lead monitoring network in response to a newer more stringent lead NAAQS, an indicator that has virtually no application beyond lead specific analyses. In contrast, combustion based pollutant measurements (SO_2, CO, NOx) in short supply have broad applications across pollutant categories and environmental media.

Transitioning research and technology development to operations. Measurement programs supported through research organizations are subject to discontinued operations compromising long term trends records and other data applications. Although analysis of long term air quality patterns is a research interest, research organizations typically focus on methods development and physicochemical process characterization with an expected transition of routine measurement programs to operational organizations. For example, NASA satellite missions typically have well defined operational time spans yet transition to longer term operational status through partner agencies generally is not planned in advance, leading to possible data record interruptions. Successful transitions include the LANDSAT mission partnership between USGS and NASA, as well as EPA's management of CASTNET which was transitioned from EPA's research to air program office in the late 1990's.

Related, the transfer of measurement technology from research to operations often is not accounted for in agencies sponsoring measurement programs; organizations perceive their priorities as being either research or operations, creating an unintended "gap"

regarding the link between both. For example, the original NCore monitoring strategy for proposed Level 1 sites was envisioned as partnerships between universities and State and local agency monitoring personnel to test emerging instrumentation and jointly share in the transition of research grade equipment to operations. Despite recommendations from EPA's Science Advisory Board (SAB), Level 1 funding has never been identified.

Market incentives. Beyond the occasional need for compliance instruments, there are few if any market incentives for instrumentation firms to pursue the engineering and development steps required to produce operational grade methods. This financial barrier is linked to the above noted issues regarding agency priorities, technology transfer and communications.

3.3 Observations and models to improve environmental characterization

Air quality models typically are used in prognostic applications that address the "what-if" questions derived from considering the effects of management programs and rules on future emissions and air quality changes – a function outside the scope of observations. More recently, air quality models have been used in current time frame applications for forecasting (next day) air pollution and providing more spatial texture beyond central site monitors to drive human exposure models. Increasingly, models and observations are being used together in a variety of ways partly due to advances in computational efficiencies and also in response to the complexities presented by multiple scales, pollutants and environmental media. Observations by themselves lack adequate resolution (space, time and composition) to support integrated assessments, and models in isolation rarely are perceived with confidence.

The integration of chemical observations and chemical transport models (CTMs) is evolving and shares common attributes with weather characterization (and forecasting), although lagging in maturation. Observation and model integration efforts range from using measurements to evaluate model performance to dynamic assimilation analogous to four dimensional data assimilation (FDDA) used in meteorological models, with several variations and intermediate levels of integration. Areas of model-observation linkages include:

- Observations supplying direct inputs for initial and/or boundary conditions;
- Observations to indirectly improve model inputs through inverse modeling of emissions;
- Observations to evaluate model performance, diagnose model behavior and constrain model adjustments;
- Observations combined or "fused" with model estimates to add spatial, temporal and compositional texture to air quality gradients; and
- Dynamic assimilation of observations to nudge model estimates, analogous to FDDA in meteorological systems.

These linkages between models and observations are emphasized here to influence a shift in monitoring design that explicitly recognizes the relationships of observations to models.

3.4 Information technology to facilitate data access, integration and use

Information technology support, which provides for archiving, accessing, retrieving and harmonizing numerous disparate information sources, is highly relevant to the multi-pollutant air quality management process. Accessing and manipulating observational data sets presents challenges to user groups accessing single database systems, which continue to be difficult despite a large investment in this essential need. Information technology applications to access and integrate data sets have reduced the burden on analysts in understanding and manipulating a variety of disparate data sets obtained in different programs. However, accessibility requirements remain a problem because of non-uniform database organization adopted by various investigators. Demands on data processing elements necessarily will increase as the breadth and depth of assessments expands through integration of observations and model output.

The U.S. EPA system for accessing air quality observations was designed primarily as a repository for data and covers only a part of the observational archives in the United States. Examples of recently developed, publicly accessible, user-friendly air-quality data reduction, integration and analysis/visualization efforts include the Visualization Information Exchange Web System (VIEWS - http://vista.cira.colostate.edu/views/) developed by the Regional Planning Organizations (RPOs) in support of visibility assessments and the Health Effects Institute's (HEI - http://hei.aer.com/login.php) air quality data base. NARSTO (http://www.narsto.org/) also has constructed an accessible database for intensive field campaigns.

The recently conceived federated data system incorporating both observations and modeling results (DataFed - http://datafedwiki.wustl.edu/index.php/DataFed_Wiki) is an outgrowth of the Global Earth Observation System of Systems (GEOSS), an attempt to coordinate earth observations catalyzed by the Group on Earth Observations (GEO, http://www.earthobservations.org/index.html). In principle, DataFed provides an architecture to facilitate interoperability of data systems from diverse organizations (shown schematically in Figure 10). Its basic concept is to link surface-based air quality data integration systems such as VIEWS with observational and modeling systems, expanding the range of environmental characterization relevant to comprehensive integrated environmental assessments. These emerging integrated systems offer potential for addressing information-technology facets of comprehensive assessments, but will require a substantial investment and engagement from supporting and user communities.

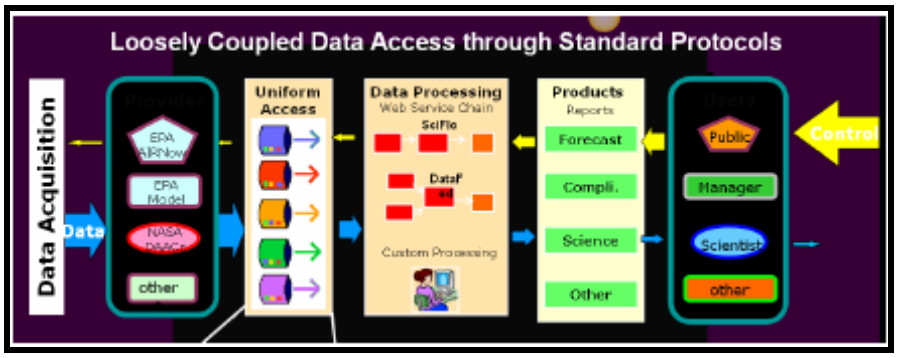

Figure 10. Concept illustration of DataFed facilitating integration across observations systems serving multiple end users (R. Husar, personal communication).

4. Recommendations

4.1 Establish a standing multi-agency observations task force

Air quality measurements are of interest to so many agencies that a broader view of the health, relevancy and evolution of observation programs should complement the existing single organization focus on discrete network elements. The charge to this task force would focus on interagency program coordination that reviews adequacy of current networks and identifies important information gaps and opportunities for advancing technology and sharing and utilization of observation programs. All of the issues raised in Section 3 would constitute the subject area for this task force. The unique contribution of this group relative to interagency review mechanisms would be the emphasis on a comprehensive integrated perspective that is either lacking or of very low priority from a single agency perspective. The task force would engage in or orchestrate periodic reviews of the "system of observation programs" probing the adequacy of our system to meet current and anticipated needs, and the modernization of technology. Key measurement gaps not met that would provide important leveraging value with existing programs would be identified, as well as inefficiencies brought about, for example, by possible redundancies among programs. Building on coordination and collaboration themes, the task force would promote information technology efforts that enhance data sharing, understanding and usefulness, recognizing the benefits of multiple user's in increasing the inherent value of observations and providing an important quality assurance feedback.

Key to the success of this group is access to key decision makers to influence needed resource allocations. The involvement of federal agencies engaged in air monitoring programs (e.g., EPA, NOAA, NASA, USDA, DOE, DOI) and associated State, local and tribal partners should be considered. Given the unlikelihood of any clear authority granted to a multi-agency task force, a charter must be developed clearly articulating responsibilities of task force members and chains of communications and methods to effect needed change in observations programs. Options, which are not mutually exclusive, include direct reporting to agency senior management and resource officials, briefings for National Academy of Science officials and relevant committees, and consideration of approaching the appropriate Congressional committees and advisory bodies to the Administration (e.g., Council on Environmental Quality (CEQ), Committee on Environmental and Natural Resources Research (CENR), Office of Science Technology and Policy (OSTP), etc.).

4.2 Address current observation gaps

An assortment of important measurements that are missing or in short supply was described in Section 3. While requests for added observations has been raised periodically, this renewed effort is intended to (a) increase the overall value to cost ratio incurred collectively through a system of measurement programs and (b) improve the comprehensive effectiveness of measurement programs where past requests have focused

on particular topics absent recognition of the broader more leverage based opportunities. Suggested steps include:

1. initiate monitoring of reactive gas and particulate nitrogen compounds, which are precursors of ozone and particulate matter, precursors of acid deposition, and act as nutrients in ecosystems,
2. collocate instrumentation at core monitoring sites to facilitate inter-comparison with satellite observations,
3. expand monitoring in rural/remote areas to measure regional backgrounds and contributions from long-range transport of pollutants,
4. establish monitoring in near-source areas to track trends and better understand observed near-source health effects, and
5. expand intensive field studies designed to elucidate critical processes that determine atmospheric concentrations of ozone and particulate matter and other air pollutants.

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Introduction to Appendices for Existing Air Quality Monitoring Programs

Observation programs supporting air quality and related assessments include routine regulatory networks, deposition networks, intensive field studies, remote sensing systems, sondes, aircraft campaigns, satellites, and focused fixed-site special purpose networks. Appendices A – H provide information on a wide variety of these air monitoring networks. Major networks that are currently operating are emphasized; reference to other networks that have been discontinued, or that were only intended for a specific operating period, is also provided. The focus is on networks located in the U.S., but attention is also given to other North American, European and international efforts that contribute to U.S. assessments.

Given the emerging themes in the main body of the report stressing integration of spatial scales, environmental media and pollutant categories, the scope of coverage providing an overview of networks is inclusive. While fixed-site, surface-based networks constitute the majority of coverage, programs providing total Earth column and vertical-profile, remote-sensing systems and dedicated vertical profiling programs are also widely used. Programs addressing climate forcing gases and aerosols, long range transport and assessment of stratospheric ozone complement the more traditional regulatory-oriented networks; they are included with the intention of exploring effective methods toward integration of the various networks to serve multiple purposes.

The information in these appendices is generally organized by measurement category covering a range of networks and programs:

Appendix A. Evolution of United States Air Monitoring Networks
Appendix B. Major Routine Operating Air Monitoring Networks
Appendix C. National Routine Meteorological Monitoring Networks
Appendix D. European Air Monitoring Networks
Appendix E. Monitoring Networks for Persistent Organic Pollutants (POPs)
Appendix F. Field Campaigns for Non-Routine Special Intensive Studies
Appendix G. Satellite - Based Air Quality Observing Systems
Appendix H. Air Monitoring Networks for Climate Forcing, Transport, Vertical Profile Information, and Stratospheric Ozone

Appendices are generally provided in table-form that includes the network name, lead agency, number of monitoring sites, the year initiated, measurement parameters (primarily air pollutants and meteorological parameters), and the Internet address for information and/or data for the network identified. Limited supplemental information is given in tables for the non-routine special intensive studies and for the satellite observing systems.

Information provided in the appendices is the product of extensive Internet searches and information provided by knowledgeable representatives of the agencies responsible for the networks. In most cases, the information provided has been taken directly from the

referenced Internet site; this is particularly true of supplemental information for the non-routine special intensive studies. Attribution of this information should be to those Internet websites.

The appendices, in addition to providing a useful reference or starting point for discussion in the body of the report, also provide a basis for addressing needed air monitoring network enhancements, whether they be for additional parameters, site locations in key rural gaps and source areas, or added vertical information. While the appendices provide only a limited factual synopsis of the air monitoring networks and data that may be available, they do provide a start for the more analytical process of identifying the value that is and is not provided by the networks. Ideally, these catalogs of monitoring networks should form a basis for assessment, i.e., the redundancies, the gaps, and the effectiveness of networks in meeting intended objectives. Such an assessment sets the stage for recommendations in the main body of this report.

Information for and comments on preliminary versions of the monitoring network tables were provided by:

Bruce Doddridge (NASA)
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Appendix A. Evolution of United States Air Monitoring Networks

The 1970 Clean Air Act (CAA) established a framework for the original National Ambient Air Quality Standards (NAAQS) and drove the design and implementation of the NAMS and SLAMS networks in the late 1970s. These networks were intended primarily to establish non-attainment areas with respect to the NAAQS which include ozone, sulfur dioxide, nitrogen dioxide, carbon dioxide, lead and particulate matter (PM). The NAMS/SLAMS networks have evolved over time (Figure A.1) as a result of cyclical NAAQS review and promulgation efforts leading to changes in measurement requirements related to averaging times, locations and the various size cuts associated with PM.

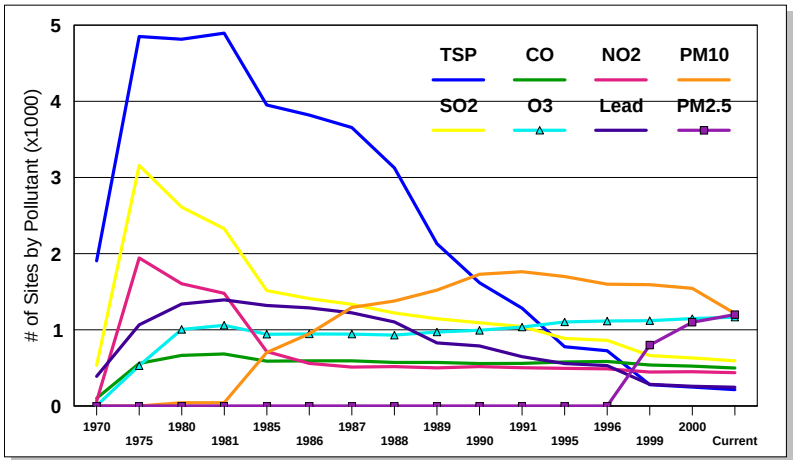

Figure A.1. Evolution of U.S. air network growth.

Relatively wide geographical distribution and persistence of ozone and $PM_{2.5}$ NAAQS exceedances (Figure A.2) have lead to these pollutants dominating the national monitoring landscape.

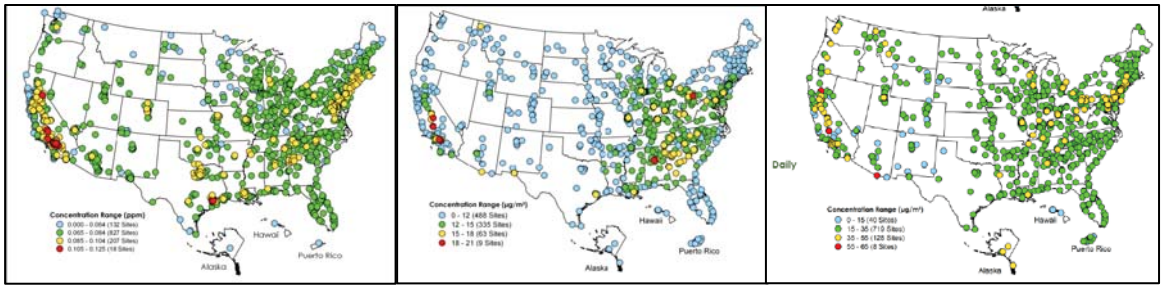

Figure A.2. 2006 air quality summaries for ozone, annual average PM2.5 and daily PM2.5. Yellow and red sites indicate values excceeding NAAQS levels (source, EPA).

Two important ambient air networks focused on environmental welfare effects were established in the mid-1980's. The Interagency Agency Monitoring of Protected Visual Environments (IMPROVE) network with over 100 sites in National Parks and other remote locations is used primarily to assess visibility impairment, but has provided a

reliable long term record of PM mass and major speciation components and served as a model for the later deployment of EPA's STN network (see Figure 2 of full report), which has provided an urban complement to characterize aerosol composition (Figure A.3).

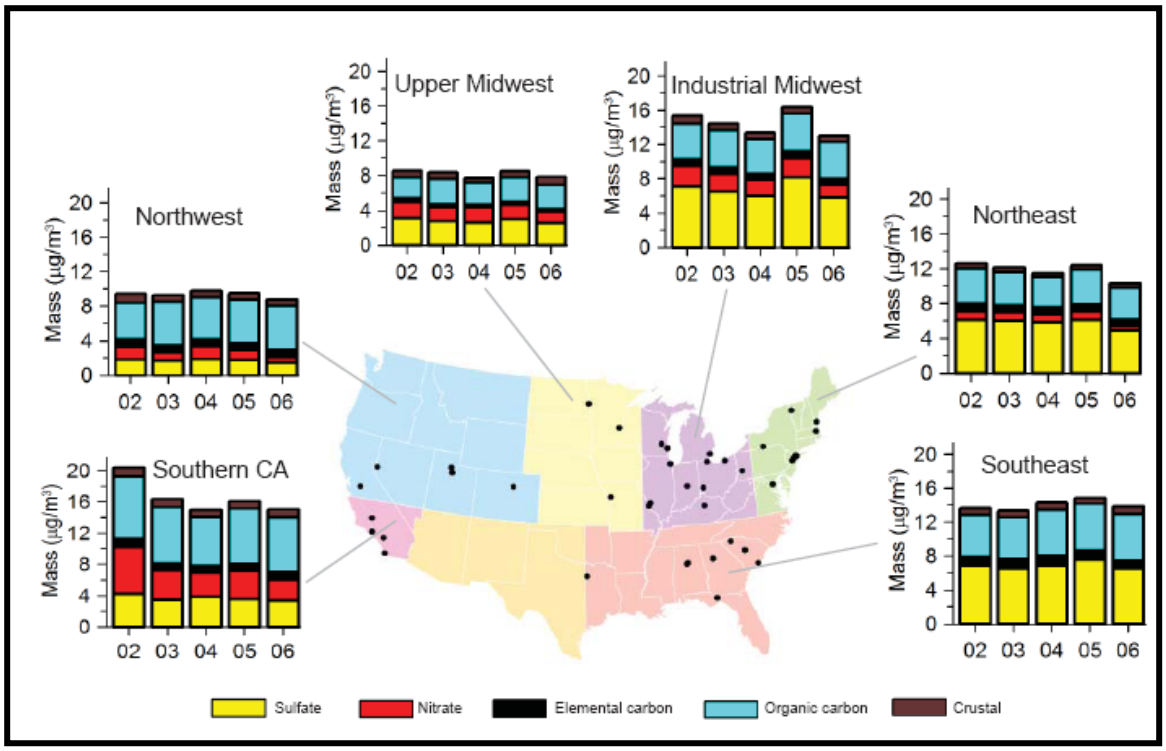

Figure A.3. Regional chemical composition of $PM_{2.5}$ aerosols based on urban speciation sites and averaged over the entire 2006 sampling period (source, 2006 EPA Air Quality Trends Report).

The Clean Air Status and Trends Network (CASTNET) was established in the early 1990s to track changes in dry deposition of major inorganic ions and gaseous precursors associated with the CAA Title 4 reductions in sulfur and nitrogen, designed to address surface water acidification in Eastern North America. Complementing ongoing precipitation measurements from the National Atmospheric Deposition Program (NADP), CASTNET has provided a valuable source of model evaluation data for many of the large regional scale applications since the 1990's.

Deployment of the Photochemical Assessment and Measurements Stations (PAMS) and the $PM_{2.5}$ networks from the early 1990's through 2002 markedly enhanced the spatial, temporal and compositional attributes of gases and aerosols, partially supporting user needs beyond NAAQS compliance (e.g., public reporting and forecasting of adverse air quality; implementation efforts including air quality model evaluation and source apportionment and pattern (spatial and temporal) analysis of precursor species.

State and local air agencies have measured a variety of metallic and gaseous hazardous air pollutants (HAPs) at over 200 locations since the 1980's. Typically, broad access and use of those data were compromised by a lack of centralized data bases and multiple

sampling and laboratory protocols enhancing data uncertainty. In response to this gap in accessible and centralized HAPs observations, a modest 23 site National Air Toxics Trends (NATTS) network was initiated in 2001. Current NATTS species include: Acrolein, Perchloroethylene, Benzene, Carbon tetrachloride, Chloroform, Trichloroethylene, 1,3-butadiene, 1,2-dichloropropane, Dichloromethane, Tetrachloroethylene, Vinyl chloride, Formaldehyde, Acetaldehyde, Nickel compounds, Arsenic compounds, Cadmium compounds , Manganese compounds,, Beryllium, Lead, Hexavalent chromium, and expected additions of Benzo(a)pyrene, Napthalene.

A new multiple pollutant monitoring network referred to as NCore was incorporated in the 2006 revisions to the particulate matter standards. When finally implemented in 2009, NCore will provide a minimum of 75 Level 2 sites (Figure A.4) in most major urban areas and important transport corridor and background locations. NCore will include a variety of trace gas, aerosol mass and speciation measurements which are intended to support multiple data user needs (e.g., air quality model evaluation, long term epidemiological studies). In addition to establishing a multiple pollutant measurement framework, the NCore sites are intended to provide a backbone of central location sites that can be complemented by additional (existing and new) stations to address more specific spatial resolution requirements. A lack of funding support has hindered implementation for more intensive Level 1 sites, intended to promote transition of new technologies into routine networks, which were endorsed by the monitoring subcommittee of the Clean Air Scientific Advisory Committee (CASAC).

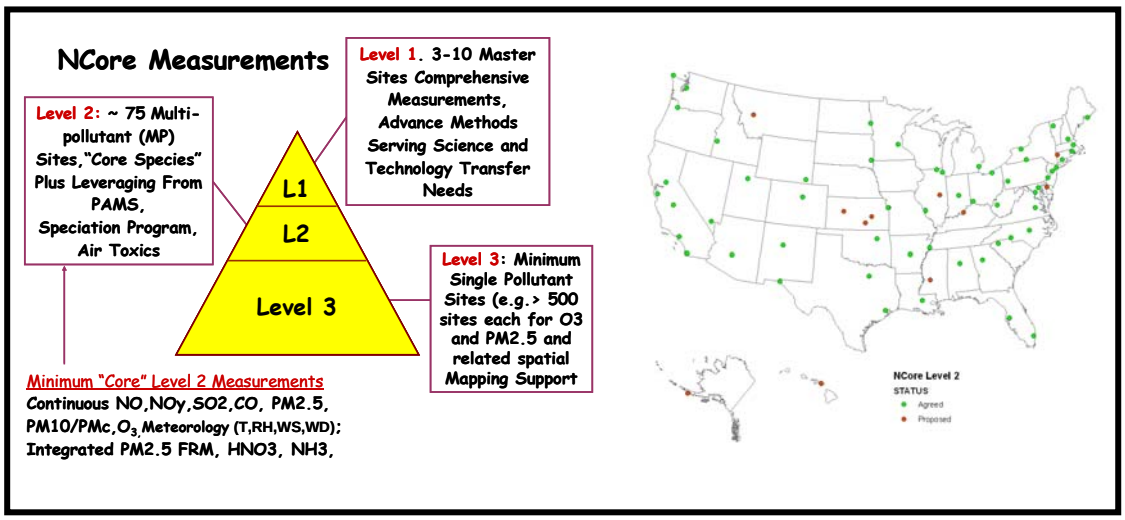

Figure A.4. Original 3-tiered NCore design (left) and proposed site locations

APPENDIX B. MAJOR ROUTINE OPERATING AIR MONITORING NETWORKS[4]

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
State / Local / Federal Networks					
NCore[1] – National Core Monitoring Network	EPA	75	2008	O3, NO/NO2/NOy, SO2, CO, PM2.5/PM10-2.5[2], PM2.5 speciation, NH3, HNO3, Surface Meteorology[2]	http://www.epa.gov/ttn/amtic/monstratdoc.html
SLAMS[1] – State and Local Ambient Monitoring Stations	EPA	~3000	1978	O3, NOx/NO2, SO2, PM2.5/PM10, CO, Pb	http://www.epa.gov/air/oaqps/ga/monprog.html
STN—PM2.5 Speciation Trends Network	EPA	300	1999	PM2.5, PM2.5 speciation, Major Ions, Metals	http://www.epa.gov/ttnamti1/specgen.html
PAMS—Photochemical Assessment Monitoring Network	EPA	75	1994	O3, NOx/NOy, CO, Speciated VOCs, Carbonyls, Surface Meteorology & Upper Air	http://www.epa.gov/air/oaqps/pams/
IMPROVE—Interagency Monitoring of Protected Visual Environments	NPS	110 plus 67 protocol sites	1988	PM2.5/PM10, Major Ions, Metals, Light Extinction, Scattering Coefficient	http://vista.cira.colostate.edu/IMPROVE/
CASTNet – Clean Air Status and Trends Network	EPA	80+	1987	O3, SO2, Major Ions, Calculated Dry Deposition, Wet Deposition, Total Deposition for Sulfur/Nitrogen, Surface Meteorology	http://www.epa.gov/castnet/
GPMN—Gaseous Pollutant Monitoring Network	NPS	33	1987	O3, NOx/NO/NO2, SO2, CO, Surface Meteorology, (plus enhanced monitoring of CO, NO, NOx, NOy, and SO2 plus canister samples for VOC at three sites)	http://www2.nature.nps.gov/air/Monitoring/network.cfm#data
POMS—Portable Ozone Monitoring Stations	NPS	14	2002	O3, surface meteorology, with CASTNet-protocol filter pack (optional) sulfate, nitrate, ammonium, nitric acid, sulfur dioxide	http://www2.nature.nps.gov/air/studies/portO3.cfm
Passive Ozone Sampler Monitoring Program	NPS	43	1995	O3 dose (weekly)	http://www2.nature.nps.gov/air/Studies/Passives.cfm
NADP/NTN—National Atmospheric Deposition Program / National Trends Network	USGS	200+	1978	Major Ions from precipitation chemistry	http://nadp.sws.uiuc.edu/
NADP/MDN—National Atmospheric Deposition Program / Mercury Deposition Network	None	90+	1996	Mercury from precipitation chemistry	http://nadp.sws.uiuc.edu/mdn/
AIRMoN—National Atmospheric Deposition Program / Atmospheric Integrated Research Monitoring Network	NOAA	8	1992	Major Ions from precipitation chemistry Note: some sites began in 1976 as part of the DOE MAP3S program; early data are archived on NADP and ARL servers.	http://nadp.sws.uiuc.edu/AIRMoN/
IADN—Integrated Atmospheric Deposition Network	EPA	20	1990	PAHs, PCBs, and organochlorine compounds are measured in air and precipitation samples	http://www.epa.gov/glnpo/monitoring/air/
NAPS—National Air Pollution Surveillance Network	Canada	152+	1969	SO2, CO, O3, NO, NO2, NOx, VOCs, SVOCs, PM10, PM2.5, TSP, metals	http://www.etc-cte.ec.gc.ca/NAPS/index_e.html
CAPMoN—Canadian Air and Precipitation Monitoring Network	Canada	29	2002	O3, NO, NO_2, NO_y, PAN, NH_3, $PM_{2.5}$, PM_{10} and coarse fraction mass, PM2.5 speciation, major ions for particles and trace gases, precipitation chemistry for major ions	http://www.msc.ec.gc.ca/capmon/index_e.cfm
Mexican Air Quality Network	Mexico	52-62	Late 1960's	O3, NOx, CO, SO2, PM10, TSP,VOC	http://www.ine.gob.mx/dgicur/calaire/indicadores.html
Mexican City Ambient Air Quality Monitoring Network	Mexico	49	Late 1960's	O3, NOx, CO, SO2, PM10, TSP,VOC	http://www.ine.gob.mx/dgicur/calaire/indicadores.html

APPENDIX B. MAJOR ROUTINE OPERATING AIR MONITORING NETWORKS[4] (continued)

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Air Toxics Monitoring Networks					
NATTS—National Air Toxics Trends Stations	EPA	23	2005	VOCs, Carbonyls, PM10 metals[3], Hg	http://www.epa.gov/ttn/amtic/airtoxpg.html
State/Local Air Toxics Monitoring	EPA	250+	1987	VOCs, Carbonyls, PM10 metals[3], Hg	http://www.epa.gov/ttn/amtic/airtoxpg.html
NDAMN—National Dioxin Air Monitoring Network	EPA	34	1998 - 2005	CDDs, CDFs, dioxin-like PCBs	http://cfpub.epa.gov/ncea/CFM/recordisplay.cfm?deid=54811
Tribal Monitoring Networks					
Tribal Monitoring[5]	EPA	120+	1995	O3, NOx/NO2, SO2, PM2.5/PM10, CO, Pb	http://www.epa.gov/air/tribal/airprogs.html#ambmon
Industry / Research Networks					
New Source Permit Monitoring	None	variable	variable	O3, NOx/NO2, SO2, PM2.5/PM10, CO, Pb	Contact specific industrial facilities
HRM Network—Houston Regional Monitoring Network	None	9	1980	O3, NOx, PM2.5/PM10, CO, SO2, Pb, VOCs, Surface Meteorology	http://hrm.radian.com/houston/how/index.htm
ARIES / SEARCH—Aerosol Research Inhalation Epidemiology Study / SouthEastern Aerosol Research and Characterization Study experiment	None	8	1992	O3, NO/NO2/NOy, SO2, CO, PM2.5/PM10, PM2.5 speciation, Major Ions, NH3, HNO3, scattering coefficient, Surface Meteorology	http://www.atmospheric-research.com/studies/SEARCH/index.html
SOS – SERON—Southern Oxidant Study - Southeastern Regional Oxidant Networks	EPA	~40	1990	O3, NO, NOy, VOCs, CO, Surface Meteorology	http://www.ncsu.edu/sos/pubs/sos3/State_of_SOS_3.pdf
National/Global Radiation Networks					
RadNet—formerly Environmental Radiation Ambient Monitoring System (ERAMS)	EPA	200+	1973	Radionuclides and radiation	http://www.epa.gov/enviro/html/erams/
SASP -- Surface Air Sampling Program	DHS	41	1963	^{89}Sr, ^{90}Sr, naturally occurring radionuclides, ^{7}Be, ^{210}Pb	http://www.eml.st.dhs.gov/databases/sasp/
NEWNET—Neighborhood Environmental Watch Network	DOE	26	1993	Ionizing gamma radiation, Surface Meteorology	http://newnet.lanl.gov/
Solar Radiation Networks					
UV Index – EPA Sunrise Program[6]	EPA	~50 U.S. cities	2002	Calculated UV radiation index	http://www.epa.gov/sunwise/uvindex.html
UV Net -- Ultraviolet Monitoring Program	EPA	21	1995/2004	Ultraviolet solar radiation (UV-B and UV-A bands), Irradiance, ozone, NO2	http://www.epa.gov/uvnet/access.html
NEUBrew (NOAA-EPA Brewer Spectrophotometer UV and Ozone Network)[7]	NOAA	6	2005	Ultraviolet solar radiation (UV-B and UV-A bands), Irradiance, ozone, SO_2	http://www.esrl.noaa.gov/gmd/grad/neubrew/

APPENDIX B. MAJOR ROUTINE OPERATING AIR MONITORING NETWORKS[4] (continued)

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Solar Radiation Networks (continued)					
UV-B Monitoring and Research Program	USDA	35	1992	Ultraviolet-B radiation	http://uvb.nrel.colostate.edu/UVB/index.jsf
SURFRAD – Surface Radiation Budget Network	NOAA	7	1993	solar and infrared radiation, direct and diffuse solar radiation, photosynthetically active radiation, UVB, spectral solar, and meteorological parameters	http://www.srrb.noaa.gov/surfrad/index.html
AERONET – Aerosol RObotic NETwork MPLNET – Micro-pulse Lidar Network	NASA co-located networks	22 + other participants 8	1998 2000	Aerosol spectral optical depths, aerosol size distributions, and precipitable water Aerosols and cloud layer heights	http://aeronet.gsfc.nasa.gov/index.html http://mplnet.gsfc.nasa.gov/
PRIMENet -- Park Research & Intensive Monitoring of Ecosystems NETwork[7]	NPS	14	1997	ozone, wet and dry deposition, visibility, surface meteorology, and ultraviolet radiation	http://www.cfc.umt.edu/primenet/Assets/Announcements/99PReport.pdf

Footnotes:

1. NCore is a network proposed to replace NAMS, as a component of SLAMS; NAMS are currently designated as national trends sites.
2. Surface Meteorology includes wind direction and speed, temperature, precipitation, relative humidity, solar radiation (PAMS only).
3. PM10 metals may include arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, and others.
4. Some networks listed separately may also serve as subcomponents of other larger listed networks; as a result, some double counting of the number of individual monitors is likely.
5. The number of sites indicated for tribal monitoring is actually the number of monitors, rather than sites. The number of sites with multiple monitors is probably less than 80.
6. Sunrise program estimates UV exposure levels through modeling - does not include measurements.
7. NEUBREW is a subset Original UV brewer network (UV Net); PRIMENET participated in UV Net program.

APPENDIX C. NATIONAL ROUTINE METEOROLOGICAL MONITORING NETWORKS

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
ASOS -- Automated Surface Observing System	NOAA	~1000 (supplemented by military weather observation sites)	1992 (replaced routine surface observations collected manually at 260 Weather Service facilities)	Continuous measurements of: Wind Direction and Wind Speed; Visibility; Runway Visual Range; Type, intensity and amount of rain, snow, etc.; Obstructions due to fog, mist, etc.; Cloud Height and Amount; Ambient Temperature; Dew Point Temperature; Pressure; Lightning detection; Automated, manual, and plain language remarks on special weather conditions (depending on level of service); and Additive and automated maintenance data on precipitation amount, max/min temperature, pressure tendency, etc.	http://www.nws.noaa.gov/asos/pdfs/aum-toc.pdf
Cooperative Observer Program	NOAA	~11,400	1890	24-hour maximum and minimum temperatures, Liquid equivalent of precipitation, snowfall, snow depth, and Other special phenomena such as days with thunder, hail, etc.	http://www.nws.noaa.gov/om/coop/coopmod.htm
SLAMS – State and Local Ambient Monitoring Stations	EPA	~3000	1978	Wind direction and speed, Temperature, Precipitation, Relative humidity	http://www.epa.gov/air/oaqps/qa/monprog.html
Remote Automated Weather Stations	DOA	~2200	~1978	Wind direction and speed, Precipitation, Pressure, Temperature, Relative humidity, Fuel moisture and temperature	http://www.fs.fed.us/raws/raws101.shtml
NOAA Profiler Network (and Cooperative Agency Profilers)	NOAA	35 (plus ~100 CAP sites)	1992	Vertical profiles of wind direction and speed (and vertical profiles of temperature at RASS sites)	http://www.profiler.noaa.gov/npn/
Upper Air Stations (Weather Balloons)	NOAA	102 in North America, Pacific Islands, and the Caribbean	1937	Measurements of temperature, relative humidity, wind direction and speed, and altitude/height at selected pressure levels.	http://www.ua.nws.noaa.gov/net-info.htm
Forecast Systems Laboratory Aircraft Communications Addressing and Reporting System	NOAA	~4000 commercial aircraft	2001 (routinely available database)	Wind direction, wind speed and temperature reported for various altitudes at which aircraft typically operate	http://acweb.fsl.noaa.gov/FAQ.html#variables
National Doppler Radar Sites	NOAA	158	1990 (national radar network originated prior to 1960)	Base Reflectivity, Composite Reflectivity, One-Hour Precipitation, and Storm Total Precipitation	http://www.srh.noaa.gov/radar/radinfo/radinfo.html
National Lightning Detection Network	Commercial	100+	1989	Detection of cloud-to-ground lightning flashes at distances up to 400 km	http://www.nwstc.noaa.gov/METEOR/Lightning/detection.htm
National Environmental Satellite, Data, and Information Service	NOAA	2 GOES satellites 2 POES satellites	1994 (earlier satellite systems replaced)	Vertical profiles of temperature, moisture, and wind; visible and infrared imagery of clouds; water vapor imagery	http://www.goes.noaa.gov/
C-MAN – Buoy and Coastal-Marine Observing Network	NOAA	70	Early 1980s	Pressure, wind direction, wind speed and gust, and air temperature, relative humidity, precipitation, visibility, sea water temperature, water level, and waves	http://www.ndbc.noaa.gov/cman.php

APPENDIX D. EUROPEAN AIR MONITORING NETWORKS

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
EMEP – Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (encompasses networks for ~37 European countries and organizations)	UNECE	270	1977	**Acidifying / Eutrophying Compounds** (precipitation): SO4, NO3, NH4, trace elements, pH, acidity (air): SO2, NO2, HNO3, NH3, PM10, PM2.5, major ions **O3** **Heavy Metals** precipitation, major ions, PM2.5, PM10, Hg, wet deposition **POPs** precipitation, air, deposition **Particulate Matter** PM2.5, PM10, EC, OC, TC, BC **VOC** Hydrocarbons, Carbonyls	http://www.nilu.no/projects/ccc/emepdata.html
EUROTRAC – The European Experiment on the Transport and Transformation of Environmentally Relevant Trace Constituents over Europe	International Executive Committee (European Countries)	???	1986	EUROTRAC programs performed analyses utilizing data from existing or specially designed monitoring networks in order to: 1. elucidate the chemistry and transport of ozone and other photo-oxidants in the troposphere, e.g., TOR -- 30 O3 stations and ALPTRAC -- 15 snow monitoring sites 2. identify processes leading to the formation of acidity in the atmosphere, particularly those involving aerosols and clouds. 3. understand uptake and release of atmospheric trace substances by the biosphere.	http://www.gsf.de/eurotrac/index_what_is.html
EUROTRAC-2 -- The EUREKA project on the transport and chemical transformation of trace constituents in the troposphere over Europe; second phase. Subprojects: – AEROSOL – BIATEX-2 – CAPMAN – CMD – EXPORT-E2 – GENEMIS – GLOREAM – LOOP – MEPOP – PROCLOUD – SATURN – TOR-2 – TRAP45 – TROPOSAT	International Scientific Secretariat (European Countries and EU)	???	1996	EUROTRAC-2 programs performed analyses utilizing data from existing monitoring networks in order to: support the further development of abatement strategies within Europe by providing an improved scientific basis for the quantification of source-receptor relationships for photo-oxidants and acidifying substances.	http://www.gsf.de/eurotrac/index_what_is.html

APPENDIX E. MONITORING NETWORKS FOR PERSISTENT ORGANIC POLLUTANTS (POPs)

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Global Monitoring of Persistent Organic Pollutants (POPs)[1]	UNEP – United Nations Environment Programme	N/A	2003	Activities include developing guidance on sampling and analysis of POPs, QA/QC procedures, data treatment and communication and data assessment. In addition the programme will include an electronic discussion group on POPs monitoring issues where existing programs and laboratories are invited to participate and share their experience on this subject.	http://www.chem.unep.ch/gmn/default.htm
AMAP – Artic Monitroing and Assessment Programme	NOAA (as U.S. representative to the 8 nation Artic Council)	???	~1991	Air/aerosol sampling for POPs, heavy metals, radioactivity and acidification parameters; bulk precipitation and snowpack sampling to estimate deposition[2]	http://www.amap.no/
EMEP -- Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe	UNECE – United Nations Economic Commission for Europe	17	1991	Benzo(a)pyrene, PCBs, hexachlorobenzene, Chlordane, lindane, hexachlorocyclohexane, DDT/DDE in precipitation and gas particles	http://www.chem.unep.ch/gmn/012_emep.htm
GAPS – Global Atmospheric Passive Sampling	UNEP – United Nations Envrionment Programme	50	2004	12 chemicals including Aldrin, Chlordane, DDT, Deldrin, Endrin, Heptachlor, Hexachlorobenzene, Mirex, PCBs, Dioxins(PCDDs), Furans(PCDFs), Toxaphene and other pollutants	http://pubs.acs.org/cgi-bin/article.cgi/esthag/2004/38/i17/html/es040302r.html
NDAMN – National Dioxin Air Monitoring Network	EPA	34	1998 - 2005	CDDs. CDFs, dioxin-like PCBs	http://cfpub.epa.gov/ncea/CFM/recordisplay.cfm?deid=54811
IADN -- Integrated Atmospheric Deposition Network	EPA	20	1990	PAHs, PCBs, and organochlorine compounds are measured in air and precipitation samples	http://www.epa.gov/glnpo/monitoring/air/
EMAP – Environmental Monitoring and Assessment Program	EPA	12,600	1988	Oriented to ecological and water monitoring	http://www.epa.gov/emap/index.html

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES[3,4]

Network	Lead Agency[1]	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data	Notes
CalNex 2010	NOAA (with CARB & CEC)	1 ship, 2 aircraft	2010	Primary pollutants (CO, NO, NO2, SO2, NMHC, CO2, NH3, PM, VOC, black carbon, and greenhouse gases); Secondary species: O3, CH2O, aldehydes, PAN, HNO3, NO3, N2O5, sulfuric acid, hydroxyl and peroxy radicals, aerosol size distribution and chemical composition; Other parameters (H2O, aerosol properties, radiation, and meteorological paramenters).	http://www.esrl.noaa.gov/csd/calnex/whitepaper.pdf	This is to be a joint field study of atmospheric processes over California and the eastern Pacific coastal region that emphasizes the interactions between air quality and climate change issues, including those affecting the hydrologic cycle. The study will constitute one of a series of comprehensive regional air quality and climate assessments conducted by NOAA with expansion of CARB's leadership of California air quality studies. It will complement the ongoing CEC regional climate change studies and will bring together specialized, complementary resources such that the outcome will be able to address important scientific questions that have an impact on environmental policy. Airborne (NOAA WP-3D Orion, NOAA Twin Otter Remote Sensing Aircraft), ship (NOAA R/V Ronald H. Brown), on-going ground-based instrument packages (upper-air observations, ground-based chemical measurements), and satellite observations (MODIS, GOES) will be employed. The collaboration of agencies will link short-term data gathered during the field program to extensive surface observations, long term data sets, and California's advanced modeling capabilities for both regional air quality and climate.
Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS / POLARCAT)	NASA (with various universities & research institutions)	3 aircraft 1 monitoring site	2008 (spring / summer)	Primary pollutants (CO, NO, NO2, SO2, NMHC, CO2, NH3, PM, VOC, black carbon, and greenhouse gases); Secondary species: O3, CH2O, aldehydes, PAN, HNO3, NO3, N2O5, sulfuric acid, hydroxyl and peroxy radicals, aerosol size distribution and chemical composition; Other parameters (H2O, aerosol properties, radiation, and meteorological parameters)	http://www.polarcat.no/activities/nasa-arctas/arctas_wp.pdf & data workshop	ARCTAS is a study of the impact of air pollution and forest fires on the arctic climate that integrates measurements from multiple aircraft and satellites. It has four major scientific themes: (1) long range transport of pollution to the Arctic including arctic haze, tropospheric ozone, and persistent pollutants such as mercury; (2) boreal forest fires and their implications for atmospheric composition and climate; (3) aerosol radiative forcing from arctic haze, boreal fires, surface deposited black carbon, and other perturbations; and (4) chemical processes with focus on ozone, aerosols, mercury, and halogens. ARCTAS is part of a larger interagency and international IPY effort collectively identified as POLARCAT which is intended to execute a series of aircraft experiments following pollution plumes as they are transported into the Arctic.
Texas Air Quality Study II (2005 - 2006)	Texas	17	2006	O3, NOx, NOy, SO2, Haze, Visibility, CO, VOC, Solar Radiation, Surface Meteorology, Upper Air	http://www.utexas.edu/research/ceer/texaqsII/PDF/12-12-04_Projected_Surface Sites_tbl.pdf	Researchers from universities, state and federal agencies, private industry, and local governments are joining forces to conduct a major field study to address air quality issues in the eastern half of Texas. The study, planned for a period extending from April 2005 through October 2006, will examine regional ozone formation, transport of ozone and ozone precursors, meteorological and chemical modeling, issues related to ozone formation by highly reactive emissions, and particulate matter formation. It is anticipated that the information from the study will be the scientific basis used for developing State Implementation Plans (SIPs) for ozone (with concentrations averaged over 8 hours), regional haze, and, if necessary, for fine particulate matter (particulate matter less than 2.5 microns in diameter, $PM_{2.5}$

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

2006 Texas Air Quality Study/ Gulf of Mexico Atmospheric Composition and Climate Study (TexAQS/GoMACCS)	NOAA	1 ship, 2 aircraft	2006	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/2006/	For TexAQS 2006, the NOAA air quality component will investigate, through airborne and sea-based measurements, the sources and processes that are responsible for photochemical pollution and regional haze during the summertime in Texas. The focus of the study will be the transport of ozone and ozone precursors within the state and the impact of the long-range transport of ozone or its precursors.
Intercontinental Chemical Transport Experiment - North America (INTEX-B) -- Intercontinental Transport and Chemical Transformation (ITCT/IGAC)	NOAA	3 aircraft	2006	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude -- NOAA aircraft	http://cloud1.arc.nasa.gov/intex-b/	The export of air pollutants from urban to regional and global environments is a major concern because of wide-ranging potential consequences for human health, cultivated and natural ecosystems, visibility degradation, weather modification, changes in radiative forcing, and tropospheric oxidizing capacity. During the spring of 2006 a highly integrated atmospheric field experiment was performed over and around North America. The Megacity Initiative: Local and Global Research Observations (MILAGRO), http://www.eol.ucar.edu/projects/milagro/, resulted through a highly coordinated collaboration between NSF (through MIRAGE-Mex), DOE (through MAX-Mex), NASA (through INTEX-B) and a variety of research institution in the U.S. and Mexico and involved ground and air borne activities centered on Mexico City, Mexico during March 2006. MILAGRO goals were greatly facilitated and enhanced by a number of concurrent and coordinated national and international field campaigns and global satellite observations. After MILAGRO, NASA continued investigating this issue, this time focusing on the influence of Asian pollutants on North America, through a second airborne field element of INTEX-B in collaboration with NSF and NCAR. The integrated goals of MILAGRO and INTEX are: -To study the extent, persistence, and transformation of Mexico City pollution plumes; -To relate atmospheric composition to sources and sinks; -To quantify radiative properties and effects of aerosols, clouds, water vapor & surfaces; -To map anthopogenic and biogenic emissions; -To characterize transport and evolution of Asian pollution to North America and beyond and determine implications for regional air quality and climate; -To achieve science-based validation of satellite observations of tropospheric composition
International Consortium for Atmospheric Research on Transport and Transformation (ICARTT)	NOAA (with various other agencies and research institutions)	Multiple aircraft and other measurement platforms	2004	Surface sites and networks, mobile platforms (aircraft and ship) and satellite data were used for measurement parameters; see http://www.esrl.noaa.gov/csd/ICARTT/fieldoperations/ for detailed information	http://www.esrl.noaa.gov/csd/ICARTT/index.shtml	ICARTT was formed to study the sources, sinks, chemical transformations and transport of ozone, aerosols and their precursors to and over the North Atlantic Ocean. Groups in North America and Europe had independently developed plans for field experiments in the summer of 2004 that shared many of the same goals and objectives in overlapping study areas; the plans were aimed at developing a better understanding of the factors that shape air quality in their respective countries and the remote regions of the North Atlantic. ICARTT was formed to take advantage of this synergy by planning and executing a series of coordinated experiments to study the emissions of aerosol and ozone precursors and their chemical transformations and removal during transport to and over the North Atlantic. The combined research conducted in the programs that make up ICARTT focus on **regional air quality**, **intercontinental transport**, and **radiation balance** in the atmosphere.

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

Intercontinental Chemical Transport Experiment - North America (INTEX-NA) -- Intercontinental Transport and Chemical Transformation (ITCT/IGAC)	NOAA	aircraft, sondes, satellites	2004	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude -- NOAA aircraft	http://cloud1.arc.nasa.gov/intex-na/desc.html	INTEX-NA is an integrated atmospheric field experiment performed over and around North America. It seeks to understand the transport and transformation of gases and aerosols on transcontinental/intercontinental scales and their impact on air quality and climate. A particular focus in this study is to quantify and characterize the inflow and outflow of pollution over North America. The main constituents of interest are ozone and precursors, aerosols and precursors, and the long-lived greenhouse gases. INTEX-NA is part of a larger international ITCT (Intercontinental Transport and Chemical Transformation) initiative. INTEX-NA goals are greatly facilitated and enhanced by a number of concurrent and coordinated national and international field campaigns and satellite observations. Synthesis of the ensemble of observations from surface, airborne, and space platforms, with the help of a hierarchy of models is an important goal of INTEX-NA.
New England Air Quality Study (NEAQS) -- Intercontinental Transport and Chemical Transformation (ITCT) 2004	NOAA	4 site, 1 ship, 2 aircraft, profiler network	2004	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/2004/	NOAA continues a joint regional air quality and climate change study combining elements of the previous NEAQS study and the Intercontinental Transport and Chemical Transformation (ITCT) research activity to focus on air quality along the Eastern Seaboard and transport of North American emissions into the North Atlantic. The major NOAA assets (the two aircraft and the ship) are deployed in a manner that supports the objectives of both components.
East Tennessee Ozone Study (ETOS)	NOAA	15+	2003	O3, Surface Meteorology	http://www.arl.noaa.gov/etos_122005.php	ETOS 2003 developed a regional ozone database to include both mean hourly averages and hourly histograms of individual measurement readings. The 2003 study period (based on scoping studies 1999 - 2002) provides a regional view to supplement Tennessee's regulatory network and serves as a demonstration and evaluation/validation database for various operational and developmental air quality forecast model components. The full scope of ETOS 2000 is continuously under planning and review, and is refined each year using the previous year's analysis and experience to focus on particular issues within the East Tennessee region.
Texas Air Quality Study (TexAQS) 2000	Texas	~20	2002	O3, NOx, PM2.5/PM10, CO, SO2, VOCs, Surface Meteorology	http://www.utexas.edu/research/ceer/texaqs/visitors/about.html	The study is designed to improve understanding of the factors that control the formation and transport of air pollutants along the Gulf Coast of southeastern Texas. Six weeks of intensive sampling, including measurements of gaseous, particulate, and hazardous air pollutants, are made at approximately 20 ground stations, located throughout the eastern half of the state. Experts in meteorology, atmospheric chemistry, and other areas of science study the formation, composition, and day-night cycles of ozone and particulate matter, as well as how these pollutants are affected by weather.
Texas Air Quality Study (TexAQS) 2000 Field Campaign	NOAA	2 aircraft	2002	O3, CO, CO2, SO2, NO, NO2, NOy, PAN, HNO3, NH3, VOCs, Solar Radiation, Meteorological Parameters, aerosols	http://www.utexas.edu/research/ceer/texaqs/visitors/about.html	Additional sampling in TexAQS 2000 is carried out with specially equipped aircraft that can detect air pollutants very quickly, at very low concentrations.

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

Bay Region Atmospheric Chemistry Experiment (BRACE)	NOAA	1 aircraft	2002	NO3, NH4, O3, SO2, NOx, CO, trace metals, particulates	http://www.dep.state.fl.us/secretary/news/2002/02-039.htm	The Florida Department of Environmental Protection (DEP), with the support of a team of federal, state, local, university and private scientists (including NOAA) conducted a month-long series of intensive studies to determine the level of influence of nitrogen deposited into Tampa Bay from local and regional sources of air pollutants on water quality. During the Bay Region Atmospheric Chemistry Experiment (BRACE), NOAA operated a research aircraft over the Tampa Bay region to collect air quality measurements of the many atmospheric forms of nitrogen and related pollutants that may potentially influence the water quality of Tampa Bay.
New England Air Quality Study (NEAQS) 2002 -- AIRMAP	NOAA	4	2002	O3, NOx, NOy, SO2, CO, VOCs, PM2.5, Precipitation Chemistry, Surface Meteorology	http://airmap.unh.edu/data/	AIRMAP is a research program focused on atmospheric chemical and physical observations in rural to semi-remote areas of New Hampshire with the goal of understanding inter-relationships in regional air quality, meteorology, and climatic phenomena. Research goals are to: (1) document and analyze current trends in the regional air quality of New England which is affected by transport from upwind regions of the U.S. and Canada and by local emission sources; (2) document and analyze current and past (the last 100 years) synoptic-to-local meteorological patterns, features, and extreme events in New England; and (3) numerically simulate the coupled evolution of atmospheric transport and chemistry in New England using various modeling tools.
New England Air Quality Study (NEAQS) 2002	NOAA	1 ship, 2 aircraft	2002	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/NEAQS/	The NOAA component of this multi-institutional effort addresses the analysis of existing climate data, and the development of new air quality monitoring programs. A background of information is to be developed that addresses New England's changing climate and air quality so as to improve understanding of the relationship between air quality and weather and determine the causes of climate change in New England
Intercontinental Transport and Chemical Transformation (ITCT) 2002 Activities	NOAA	1 site, 1 aircraft	2002	CO2, CO, CH4, SO2, O3, SF6, N2O, CFCs, Aerosols, Solar Radiation, Surface Meteorology & Upper Air -- surface. O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air -- aircraft	http://esrl.noaa.gov/csd/ITCT/2k2/	This field program, scheduled for spring 2002 to investigate the composition of air masses along the Pacific coast of North America, is part of the Intercontinental Transport and Chemical Transformation (ITCT) research activity of the International Global Atmospheric Chemistry Program (IGAC) Program. Goals of this field study are to: characterize the chemical composition of the air masses coming ashore at the West Coast; explore the composition of these air masses as they are transported inland; and investigate the alteration in composition associated with the addition of emissions from U.S. West Coast sources. The NOAA WP-3D aircraft is to deploy a wide array of instrumentation for the in situ measurement of gaseous and aerosol parameters plus radiation and remote aerosol sensing by LIDAR. The Trinidad Head baseline observatory characterizes chemical composition of marine boundary layer at the U.S. West Coast and provides linkage between composition measurements and radiative properties of the aerosols. The NOAA ETL Laboratory network of 915-MHz radar wind profilers that are deployed in California provide additional meteorological information.

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

TRAnsport and Chemical Evolution over the Pacific (TRACE-P)	NASA	2 aircraft	2001 (2 months)	O3, NO, NO2, N2O, CH4, SO2, NH3, CO, CO2, aerosols, PAN, HNO3, aldehydes, peroxides, speciated hydrocarbons, other pollutants, meteorological parameters	http://www-gte.larc.nasa.gov/gte_fld.htm#TRACE	TRACE-P is part of a series of aircraft missions aimed at better understanding of global tropospheric chemistry, and more specifically in this case, the effects of outflow from the Asian continent on the composition of the global atmosphere. Objectives are to determine: (1) pathways for outflow of chemically and radiatively important gases and aerosols, and their precursors, from eastern Asia to the western Pacific; and (2) the chemical evolution of the Asian outflow over the western Pacific, and the ensemble of processes that control this evolution. Approximately 20 aircraft measurement flights involving horizontal and vertical profiles for a total of over 300 hours were supported by surface based measurements and soundings.
Aerosol Characterization Experiments - Asia (ACE-Asia)	NSF	sites, ships, aircraft, satellites	2001 (spring)	aerosol chemical, physical, and radiative properties and radiative fluxes, meteorological parameters	http://saga.pmel.noaa.gov/Field/aceasia/ACEAsiaDescription.html	The Aerosol Characterization Experiments (ACE) are designed to increase understanding of how atmospheric aerosol particles affect the Earth's climate system. ACE-Asia took place during the spring of 2001 off the coast of China, Japan and Korea which includes many types of aerosol particles of widely varying composition and size. These particles include those emitted by human activities and industrial sources, as well as wind-blown dust. Data from ACE-Asia is improving understanding of how atmospheric aerosols influence the chemical and radiative properties of the Earth's atmosphere.
Central California Ozone Study (CCOS)[2]	California	100+ sites, 6 aircraft, profilers, sondes	2000	O3, VOC, NOx, NO, NOy, CO, PM10, PM2.5, solar radiation, surface meteorology, upper air	http://www.arb.ca.gov/airways/	For the summer season, this study collected meteorological and air quality data for the central section of California in 2000. Planes and weather balloons collected data at ground level and aloft. The data collected is used to improve the understanding of the role of meteorology on the formation and behavior of air pollutants and their precursors and emission sources and patterns. The information gathered will be used to develop an improved modeling system that will be used in preparing plans to attain the new federal 8-hour ozone standard, as well as to update the Clean Air Plan to attain the state ozone standard.
California Regional Particulate Air Quality Study (CRPAQS)[2]	California	~60	1999 to 2001	PM2.5, PM10, nephelometer, with some sites adding SO4/NO3, OC/EC, NO2, NOy, PAN, SO2, surface meteorology	http://www.arb.ca.gov/airways/	The California Regional PM10/PM2.5 Air Quality Study is a comprehensive public/private sector collaborative program to provide an improved understanding of particulate matter and visibility in central California. It is intended to evaluate both the national and State air quality standards for PM10 and PM2.5. The field programs consisted of 14 months of monitoring throughout the San Joaquin Valley (SJV) and surrounding regions, as well as intensive monitoring during summer, fall, and winter seasonal periods.
Southern Oxidant Study (SOS) 1999 Field Campaign -- Nashville	NOAA	3 sites, 4 aircraft	1999	O3, NO, NO2, NOy, VOCs, aerosols, Surface Meteorology & Upper Air (profiler), ozonesonde -- surface O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude -- aircraft	http://esrl.noaa.gov/csd/SOS99/	The Southern Oxidants Study (SOS), in collaboration with other organizations and programs, conducted this major Field Campaign during June/July 1999. The Nashville/Middle Tennessee region measurements focused on an improved understanding of the processes that control the formation and distribution of fine particles and ozone. Three study themes were: Local vs. regional contrasts, Ozone and PM formation in plumes, and diurnal cycle in chemistry and meteorology. These themes were addressed through a series of coordinated measurements involving instrumented aircraft and a ground-based network of chemistry and meteorological measurements.

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

PM Supersite Program	EPA	2 Phase I Sites 7 Phase II Sites	1999	Measurement may include: PM2.5, PM10, TSP, SO4, NO3, EC, OC, light absorption & extinction, O3, CO , NOx, NO, NO2, NOy, HNO3, NH3, VOCs, Carbonyls, PAH, major ions and elements, surface and upper air meteorology	http://www.epa.gov/ttn/amtic/supersites.html	In response to Executive and Congressional mandates and recommendations from the National Research Council a "Supersites Conceptual Plan" was developed and implemented. Atlanta and Fresno were selected as initial Phase I sites and as a result of a competitive process Baltimore, Fresno, Houston, Los Angeles, New York, Pittsburgh, and St. Louis were selected for Phase II. Goals generally were to characterize particulate matter, support health effects and exposure research, and conduct methods testing. Extensive monitoring, data analysis, and publication continued to 2005 with the preparation of a Final Report for each city.
Big Bend Regional Aerosol and Visibility Observational (BRAVO) Study	NPS/EPA	38 fixed, 6 tracer sites	1999	SO2, SO4, PM2.5, NO3, NH4, major ions and elements, nephelometer, transmissometer, meteorological parameters & upper air, PFC tracer	http://www.dri.edu/Home/Features/text/BRAVO.htm	The BRAVO study was conducted for four months during 1999 with the primary objective of identifying the causes of haze in the Big Bend National Park located in West Texas. This very large, collaborative study enlisted numerous participants with sponsorship from federal/State agencies, private industry, and research organizations. The BRAVO study utilized data from a 38-site network to characterize spatial and temporal aerosol patterns in the atmosphere. In addition, upper-air measurements and extensive optical measurements of light scattering and absorption were made. Because monitoring and source characterization activities were conducted only in the United States, the study design included additional monitoring and tracer studies along the U.S./Mexican border.
Indian Ocean Experiment (INDOEX)	UCSD	6 sites, 2 ships, 5 aircraft, satellites	1999 (4 months)	O3, NO, NO2, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, trace gases, aerosols, meteorological parameters & upper air	http://data.eol.ucar.edu/codiac/projs?INDOEX	The Indian Ocean Experiment (INDOEX) addresses questions of climate change through collection of in-situ data on the regional cooling effect of sulfate and other aerosols. The project's goal is to study natural and anthropogenic climate forcing by aerosols and feedbacks on regional and global climate. INDOEX field studies occur where pristine air masses from the southern Indian Ocean including Antarctica and not-so-clean air from the Indian subcontinent meet over the tropical Indian Ocean to provide a unique natural laboratory for studying aerosols. Scientists collect data from the water surface through the lower stratosphere, on the aerosol composition, reactive atmospheric gases, solar radiation fluxes, wind and water vapor distribution. To this end, investigators use multiple aircraft, ships and island stations over the Arabian Sea and the Indian Ocean.
Eulerian Model Evaluation Field Study (EMEFS)	Canada	~135	1998	O3, NO2, SO2, NH3, HNO3, major ions,	http://www.msc-smc.ec.gc.ca/natchem/particles/n_emefs_e.html	Under EMEFS, air and precipitation chemistry data were collected daily for two years over much of the eastern United States and Canada to provide data for assessing the performance of acid deposition and other regional scale models.
NARSTO-Northeast 1995	Multiple	559	1995	O3, NO, NOx	http://www.narsto.org/section.src?SID=9	Measurements were made during the NARSTO-Northeast 1995 intensive field campaign during the period May through September. One-hour average O3, NO, and NOX measurement results are reported for ground surface monitoring stations operated by various agencies including EPA AIRS, CASTNet, ESE, Harvard University, NYSEG, PEPCO, and the University of Maryland.

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

SOS Nashville/Middle Tennessee Ozone Study	TVA	116	1994-1995	O3, SO2, NO, NOy, and CO, VOC, Surface Meteorology, rawinsonde and ozonesonde releases, and a radar profiler/radar acoustic sounding system. -- surface Airborne ozone and aerosol lidar – aircraft	http://www.ncsu.edu/sos/pubs/sos2/State_of_SOS_2.pdf	This ozone-focused field study was carried out in the 11-state region surrounding Nashville/Middle Tennessee, beginning with a 3-week exploratory study during the summer of 1994 and culminating in a six-week field measurement campaign June/July 1995. Measurements were taken at 116 ground-based and tall building and tower-based chemical and meteorological measurement sites and a series of six airborne chemical measurement platforms. The most significant feature of the Nashville/Middle Tennessee Ozone Study was a coordinated series of 40+ aircraft studies to measure physical and chemical characteristics of urban and industrial plumes. (Note: an earlier ozone-focused set of field studies was also conducted in the Atlanta, GA area during the summers of 1990 - 1992.)
North Atlantic Regional Experiment (NARE)	NOAA	various sites, 1 ship	1993	O3, NO, NO2, NOx, NOy, VOC, Surface Meteorology	http://www.igac.noaa.gov/newsletter/24/introduction.php	The NARE program measured the type and amount of air pollutants being transported from the North American continent to the Northern Atlantic Ocean. Since the Northeast United States and Nova Scotia, Canada are the last land locations as air masses move out over the ocean, measurements were made a number of land and island sites in Maine, Nova Scotia, and Sable Island. Acadia National Park participated in this study

Footnotes:

1. EPA -- Environmental Protection Agency
   NASA -- National Aeronautics and Space Administration
   NOAA -- National Oceanic and Atmospheric Administration
   NPS -- National Park Service
   NSF -- National Science Foundation
   CARB -- California Air Resources Board
   CEC -- California Energy Commission
   UCSD -- University of California San Diego (Scripts Institution of Oceanography)

2. This study is part of the Central California Air Quality Studies (CCAQS) which comprise the California Regional Particulate Air Quality Study (CRPAQS) and the Central California Ozone Study (CCOS). CCAQS is a multi-year effort of meteorological and air quality monitoring, emission inventory development, data analysis, and air quality simulation modeling. Prior studies in California included: Southern California Ozone Study (SCOS97) -- 1997; Integrated Monitoring Study (IMS95) -- 1995; San Joaquin Valley Air Quality Study (SJVAQS) -- 1990; SARMAP Ozone Study -- 1990; Southern California Air Quality Study (SCAQS) -- 1987.

3. Historically, there have been many other field studies in the 1960's - 1990's that are not reflected in this table that involve both fixed monitoring sites and aircraft; well known examples include Regional Air Pollution Study (RAPS), Large Power Plant Effluent Study (LAPPES), Northeast Corridor Regional Modeling Program (NECRMP), Northeast Regional Oxidant Study (NEROS), Persistent Elevated Pollutant Episode (PEPE), and Lake Michigan Ozone Study (LMOS).

4. In addition to the air monitoring networks and related studies detailed in this table that are primarily concerned with lower tropospheric air pollution, there are a large number of observations and studies conducted by NASA, NOAA and others that address such topics as (1) upper tropospheric and stratospheric ozone and aerosols, (2) cloud processes, and (3) validation experiments for satellite observations. These studies include but are not limited to:
-- Stratospheric Tropospheric Exchange Project (STEP) – 1987
-- Airborne Antarctic Ozone Experiment (AAOE) – 1987

-- Airborne Arctic Stratospheric Experiment (AASE) – 1989
-- Airborne Arctic Stratospheric Experiment II (AASE2) – 1992
-- Stratospheric Photochemistry Aerosols and Dynamics Experiment (SPADE) – 1993
-- Airborne Southern Hemisphere Ozone Experiment / Measurements for Assessing the Effects of Stratospheric Aircraft (ASHOE/MAESA) – 1994
-- Stratospheric Tracers of Atmospheric Transport (STRAT) – 1995-1996
-- Tropical Ozone Transport Experiment (TOTE) and Vortex Ozone Transport Experiment (VOTE) – 1995-1996
-- Subsonic Aircraft: Contrail and Clouds Effects Special Study (SUCCESS) – 1996
-- Photochemistry and Ozone Loss in the Arctic Region in Summer (POLARIS) – 1997
-- Subsonic Assessment: Ozone and Nitrogen Oxide Experiment (SONEX) – 1997
-- Texas Florida Underflights A (TEFLUN) – 1998
-- The Third Convection and Moisture Experiment (CAMEX 3) – 1998
-- TRMM Brazil Validation Experiment (TRMM-LBA) – 1999
-- TRMM Kwajalein Validation Experiment (KWAJEX) – 1999
-- Nauru 1999 Field Campaign – 1999
-- South African Fire-Atmosphere Research Initiative 2000 (SAFARI) – 2000
-- SAGE III Ozone Loss and Validation Experiment (SOLVE) – 1999-2000
-- ERAST Predator-B RPV Homepage (ERAST) – 2000
-- CAMEX 4 The Fourth Convection and Moisture Experiment (CAMEX 4) – 2001
-- East Pacific Investigation of Climate (EPIC) 2001 Field Program – 2001
-- The Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL FACE) – 2002
-- The SAGE III Ozone Loss and Validation Experiment (SOLVE II) – 2003
-- The Aura Validation Experiment (AVE) – 2004
-- The Intercontinental Chemical Transport Experiment – North America (INTEX-NA) – 2004
-- The Aura Validation Experiment Houston (AVE Houston) – 2004
-- North American Monsoon Experiment (NAME) – 2004
-- Winter Storms Reconnaissance Program 2004 (WSR2004) – 2004
-- Polar Aura Validation Experiment (PAVE) – 2005
-- The Tropical Cloud Systems and Processes Mission (TCSP) – 2005
-- UAS Flight Demonstration Project 2005 – 2005

APPENDIX G. SATELLITE – BASED AIR QUALITY OBSERVING SYSTEMS[1]

Instrument	Satellite Platform[4]	Lead Agency	Initiated	Measurement Parameters[2]	Orbit & Horizontal Resolution	Location of Information and/or Data
OLS (Operational Linescan System)	DMSP satellites	DOD	1962?	Identify fires and smoke plumes	Polar Imagery only	http://www.af.mil/factsheets/factsheet.asp?fsID=94
BUV (Backscatter Ultraviolet Spectrometer)	Nimbus 4	NASA	1970-1980	O3, CO2, SO2	Sun synchronous	http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=1970-025A
SBUV (Solar Backscatter Ultraviolet Spectrometer)	Nimbus 7	NASA	1978-1993	O3, SO2	Polar	http://jwocky.gsfc.nasa.gov/n7toms/nimbus7tech.html
TOMS (Total Ozone Mapping Spectrometer)	Nimbus 7 Meteor 3 Earth-Probe	NASA	1978-1993 1991-1994 1996	O3, SO2, Aerosols	Polar ~100km^2	http://toms.gsfc.nasa.gov/fltmodel/spacecr.html
LIMS (Limb Infrared Monitor of the Stratosphere)	Nimbus 7	NASA	1978-1979	O3, HNO3, NO2,	Polar	http://toms.gsfc.nasa.gov/n7toms/nimbus7tech.html
ATMOS (Atmospheric Trace Molecule Spectroscopy)	Spacelab 3 ATLAS -- 1,2,3	NASA	1985, 1992, 1993, 1994	O3, CFCl3, CF2Cl2, ClONO2, HCl, HF, CO, CH4, HCN, HNO3, NO, NO2, N2O, N2O5, Aerosols		http://remus.jpl.nasa.gov/atmos/sl3.html
CLAES (Cryogenic Limb Array Etalon Spectrometer)	UARS	NASA	1991-1993	O3, CFCl3, CF2Cl2 ClONO2, CH4, HNO3, NO, NO2, N2O, N2O5, Aerosols		http://umpgal.gsfc.nasa.gov/
HALOE (Halogen Occultation Experiment)	UARS	NASA	1991-2005	O3, HCl, HF, CH4, NO, NO2, Aerosols		http://umpgal.gsfc.nasa.gov/
ISAMS (Improved Stratospheric and Mesospheric Sounder)	UARS	NASA	1991-1992	O3, CO, CH4, NO2, N2O, N2O5, Aerosols		http://umpgal.gsfc.nasa.gov/
MLS (Microwave Limb Sounder)	UARS	NASA	1991-1999	O3, ClO, CH3CN, HNO3, SO2		http://umpgal.gsfc.nasa.gov/
GOES Imager (Geostationary Operational Environmental Satellites)	GOES-10 GOES-12	NOAA	1994	Fire products for WF_ABBA (imagery) and GASP (aerosol optical depth)	Geostationary 4x4 km^2	http://www.nesdis.noaa.gov/sat-products.html
GOES Sounder (Geostationary Operational Environmental Satellites)	GOES-10 GOES-12	NOAA	1994	Total column O3	Geostationary	http://cimss.ssec.wisc.edu/goes/data.html
AVHRR[3] (Advanced Very High Resolution Radiometer)	NOAA-15 NOAA-16 NOAA-17 NOAA-18	NOAA	1998	Aerosol optical depth, particle size information and vegetation/drought index products related to air quality through fires	Polar ~1x1 km^2	http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html
SBUV/2[3] (Solar Backscattered Ultraviolet Radiometer Model 2)	NOAA-16 NOAA-17 NOAA-18	NOAA	2000	Total and profile O3 from surface to top of atmosphere in ~5 km thick Umkehr layers	Polar	http://www.ozonelayer.noaa.gov/action/sbuv2.htm

APPENDIX G. SATELLITE – BASED AIR QUALITY OBSERVING SYSTEMS[1] (continued)

MOPITT (Measurement of Pollution in the Troposphere)	EOS Terra	NASA	1999	CO, CH4	Polar 22 x 22 km^2	http://www.eos.ucar.edu/mopitt/
MISR (Multi-angle Imaging SpectroRadiomenter)	EOS Terra	NASA	1999	Aerosol properties and plume height information near the vicinity of fires	Polar ~1x1 km^2	http://www-misr.jpl.nasa.gov/mission/introduction/welcome.html
MODIS (Moderate Resolution Imaging Spectroradiometer)	EOS Terra EOS Aqua[5]	NASA	1999 2002	O3, Aerosol optical depth, particle size information, fine particle fraction, and forest fires	Polar ~1x1 km^2	http://modarch.gsfc.nasa.gov/index.php
AIRS (Atmospheric Infrared Sounder)	EOS Aqua[5]	NASA	2002	Total column ozone, surface temperature, temperature and moisture vertical profiles, (plus under development are CO and CO2 total column, O3 vertical distribution, and CH4 distribution)	Polar 50km	http://airs.jpl.nasa.gov/
HIRDLS (High Resolution Dynamics Limb Sounder)	EOS Aura[5]	NASA	2004	O3, CFC11, CFC12, ClONO2, CH4, HNO3, NO2, N2O, N2O5, Aerosols	Polar	http://aura.gsfc.nasa.gov/index.html http://www.nasa.gov/mission_pages/aura/spacecraft/index.html
MLS (Microwave Limb Sounder)	EOS Aura[5]	NASA	2004	O3, BrO, ClO, HOCl, HCl, CO, HCN, CH3CN, HNO3, N2O, OH, HO2	Polar	http://aura.gsfc.nasa.gov/index.html http://www.nasa.gov/mission_pages/aura/spacecraft/index.html
OMI (Ozone Monitoring Instrument)	EOS Aura[5]	NASA	2004	O3, BrO, OClO, HCHO, NO2, SO2 and aerosols	Polar 48 x 48 km^2	http://aura.gsfc.nasa.gov/index.html http://www.nasa.gov/mission_pages/aura/spacecraft/index.html
TES (Total Emission Spectrometer)	EOS Aura[5]	NASA	2004	O3, NOy, CO, SO2, CH4	Polar 26 x 42 km^2	http://aura.gsfc.nasa.gov/index.html http://www.nasa.gov/mission_pages/aura/spacecraft/index.html
CALIPSO (Cloud-Aerosol Lidar & Infrared Pathfinder Satellite Observations)	CALIPSO[5]	NASA	2005	Aerosol optical depth, backscatter, extinction	Polar 0.3 x 0.3 km^2	http://www-calipso.larc.nasa.gov/about/
OMPS (Ozone Mapping and Profiling Suite)	NPOESS - Preparatory Project	NOAA	2006	Total column and vertical profile ozone data	Polar	http://www.ipo.noaa.gov/index.php?pg=proj
VIIRS (Visible Infrared Imaging Radiometer Suite)	NPOESS - Preparatory Project	NOAA	2006	Aerosol optical depth	Polar	http://www.ipo.noaa.gov/index.php?pg=proj
Orbiting Carbon Observatory	OCO[5]	NASA	2009 (failed)	CO2	Polar	http://oco.jpl.nasa.gov/
APS & TIM (Aerosol Polarimetry Sensor & Total Irradiance Monitor)	Glory	NASA	2009 (planned)	Black carbon soot, other aerosols, total solar irradiance, cloud images	Sun- synchronous, circular, Low Earth Orbit	http://glory.gsfc.nasa.gov/
SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography)	Envisat	ESA	2002	Total column for O3, NO2, BrO, OClO, SO2, HCHO, aerosols	Polar 60 x 30 km^2	http://envisat.esa.int/instruments/sciamachy/
GOME & GOME-2 (Global Ozone Monitoring Experiment)	ERS-2 MetOp-A	ESA	1995 2006	Total column for O3, NO2, BrO, SO2, HCHO, aerosols	Polar 40 x 40 km^2	http://earth.esa.int/ers/gome/ http://www.esa.int/esaLP/SEMTTEG23IE_LPmetop_0.html

Footnotes:

1. Some instrument systems listed (e.g., UARS/HALOE) are oriented primarily to stratospheric measurements and may have limited application to the troposphere.
2. Note that many of the satellite instruments also have the capability to measure temperature, H_2O and other parameters.
3. NOAA satellites as early as 1978 have carried AVHRR, and as early as 1985 have carried BUV/2
4. CALIPSO -- Cloud-Aerosol Lidar & Infrared Pathfinder Satellite Observations
   DMSP -- Defense Meteorological Satellite Program
   EOS -- Earth Observing System
   ESA -- European Space Agency
   GOES -- Geostationary Operational Environmental Satellites
   NASA -- National Aeronautics and Space Administration
   NOAA -- National Oceanic and Atmospheric Administration
   NPOESS -- National Polar-orbiting Operational Environmental Satellite System
   OCO -- Orbiting Carbon Observatory
   UARS -- Upper Atmosphere Research Satellite
5. This satellite is part of the A-Train group of satellites. It will involve for the first time satellites flying in a formation that crosses the equator one satellite at a time, a few minutes apart, at around 1:30 pm local time. The A-Train is made up of Aqua, Aura, CALIPSO, and will include Glory in 2009; it also includes CloudSat (2005) – data on the structure of ice and water clouds, and PARASOL (2004) – data on the directional characteristics and polarization of light reflected by the Earth and atmosphere, including aerosol optical depth. Together their overlapping science instruments will give a comprehensive picture of Earth weather and climate.

APPENDIX H.
AIR MONITORING NETWORKS FOR CLIMATE FORCING, TRANSPORT, VERTICAL PROFILE INFORMATION, AND STRATOSPHERIC OZONE

Network	Lead Federal Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Global Monitoring Division Baseline Observatories					
Mauna Loa	NOAA	1	1957	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/mlo/
Point Barrow	NOAA	1	1973	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/brw/
Samoa	NOAA	1	1974	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/smo/
South Pole	NOAA	1	1957	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/spo/
Trinidad Head	NOAA	1	2002	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/thd/
Global Monitoring Division -- Carbon Cycle Greenhouse Gases Group (CCGG)					
Observatory Measurements	NOAA	4	1957	See above baseline observatories	http://www.cmdl.noaa.gov/ccgg/insitu.html
Cooperative fixed sites	NOAA	62	1967	CO2, CH4, CO, H2, N2O, and SF6, stable isotopes of CO2 and CH4	http://www.cmdl.noaa.gov/ccgg/flask.html
Commercial Ships	?????	?????	?????		
University of Washington					
Cheeka Peak Observatory	None	1	1997	O3, CO, Aerosols, Solar Radiation, Surface Meteorology	http://www.washington.edu/research/field/
Mt. Bachelor Observatory	None	1	2004	O3, CO, NO/NO2, Aerosols, Hg, Surface Meteorology	http://research.uwb.edu/jaffegroup/modules/mbo_plot/
Vertical Profile and Other Measurement Networks					
ALE / GAGE / AGAGE Network	NASA	5 Current 2 Discontinued	1978	CO, CH4, SF6, N2O, H2, CFCs, HCFCs, HFC's, methyl chloroform, carbon tetrachloride, chloroform, perchloroethylene, halons & others	http://cdiac.ornl.gov/ndps/alegage.html
Tall Tower Measurements	NOAA	8	1992	CO2, CO, CH4, H2, CFCs, methyl chloroform, carbon tetrachloride, chloroform, sulfur hexafluoride, perchloroethylene	http://www.esrl.noaa.gov/gmd/ccgg/towers/index.html http://www.nacarbon.org/cgi-nacp/web/investigations/inv_pgp.pl?pgid=171
Research Wind Profiler Network	NOAA	variable	???	Vertical wind and temperature profiles, surface meteorology	http://www.etl.noaa.gov/et7/data/
REALM – Regional East Atmospheric Lidar Mesonet	NOAA	13	2004	Lidar measurements for mixing height and vertical profiling of aerosols, ozone and water vapor	http://alg.umbc.edu/REALM/
Ozonesonde Network	NOAA	3 (9?)	???	Weekly Upper Air measurements of ozone, temperature, and humidity information from surface to approximately 32 km	http://www.cmdl.noaa.gov/ozwv/ozsondes/
SHADOZ Network (Southern Hemisphere ADditional Ozonesondes)	NASA	12	1998	Upper air measurements of ozone, temperature, and humidity	http://croc.gsfc.nasa.gov/shadoz/

APPENDIX H.
AIR MONITORING NETWORKS FOR CLIMATE FORCING, TRANSPORT, VERTICAL PROFILE INFORMATION, AND STRATOSPHERIC OZONE (continued)

Aircraft Measurements	NOAA	16 airport sites	1992	CO2, CH4, N2O, CO, H2, SF6	http://www.cmdl.noaa.gov/ccgg/aircraft.html http://www.nacarbon.org/cgi-nacp/web/investigations/inv_pgp.pl?pgid=171
Networks for Halogenated Gases and Ozone	NOAA	Multiple platforms	1986	nitrous oxide (N2O), CFCs, HCFCs, HFCs, CH3Br, CH3Cl, CH3I), halons	http://www.cmdl.noaa.gov/hats/
Network for Aerosols	NOAA	Multiple platforms	mid-1970s	light absorption, total scattering and backscattering	http://www.cmdl.noaa.gov/aero/
Ameriflux CO2 exchange network	DOE, NOAA, USDA, NASA	~50 Micrometero logical towers	1996	CO2, meteorological variables	http://public.ornl.gov/ameriflux/index.html
FluxNet CO2 exchange network	International	~150 Micrometero logical towers	1996	CO2, meteorological variables	http://www.fluxnet.ornl.gov/fluxnet/index.cfm
North American Carbon Program Atmospheric Observing System	Multiple participants	Multiple platforms	2001	CO, CO2, CH4	http://www.nacarbon.org/nacp/
AERONET -- AErosol RObotic NETwork MPLNET – Micro-pulse Lidar Network	NASA co-located networks	22 + other participants 8	1998 2000	Aerosol spectral optical depths, aerosol size distributions, and precipitable water Aerosols and cloud layer heights	http://aeronet.gsfc.nasa.gov/index.html http://mplnet.gsfc.nasa.gov/
International Aircraft Measurements					
MOZAIC (Measurement of ozone, water vapour, carbon monoxide and nitrogen oxides aboard Airbus in-service aircraft)	None	2500 Airbus international flights/year	1994	O3, H2O, CO, NOx	http://www.fz-juelich.de/icg/icg-ii/mozaic/home
NOXAR (Measurements of Nitrogen Oxides and Ozone Along Air Routes)	None	500 Swiss Air flights to U.S. and far east	1995 - 1996	O3, NO, NO2	http://www.iac.ethz.ch/en/research/chemie/tpeter/Noxar.html
CARIBIC (Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container)	None	~100 Lufthansa flights	1997	CO, O3, CO, CH4, CO2, N2O, SF6, NMHC, Position & Meteorology and Cloud cover.	http://www.caribic-atmospheric.com/
AMATRAS (Atmospheric Measurement by Airliners for Trace Species)	None	262 flights between Japan and Australia	1993	CO2, CH4, CO and SF6	http://www.jal.com/en/press/000033 6/img/AMATRAS.pdf
NOAA Research Observing Systems (Systems typically incorporated in intensive field campaigns)					
R/V Ronald H. Brown, Lockheed WP-3D Twin Otter	NOAA	ship aircraft aircraft	???	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air, altitude	http://esrl.noaa.gov/csd/2006/p3science.html